BRUCE

VOLUME 24 MAY, 1936 NUMBER 5

PROCEEDINGS
of
The Institute of Radio Engineers

Eleventh Annual Convention
Cleveland, Ohio
May 11, 12, and 13, 1936

Application Blank for Associate Membership on Page XIII

INSTITUTE OF RADIO ENGINEERS

ELEVENTH ANNUAL CONVENTION

HOTEL STATLER, CLEVELAND, OHIO

MAY 11, 12, AND 13, 1936

Sunday—May 10

4:00 P.M.–6:00 P.M.	Registration

Monday—May 11

9:00 A.M.	Registration and opening of exhibition.
10:30 A.M.–12:30 P.M.	Official Welcome and Technical Session.
10:30 A.M.– 1:00 P.M.	Ladies meet in Parlor 1.
12:30 P.M.– 2:00 P.M.	Luncheon and inspection of exhibits.
1:00 P.M. Trip No 1.	Ladies luncheon and visit to Higbee Department Store and WHK Studios.
2:00 P.M.– 4:15 P.M.	Technical Session—Ballroom.
6:00 P.M.	Close of registration and exhibition.

Tuesday—May 12

9:00 A.M.	Registration and opening of exhibition.
10:00 A.M.–12 noon	Technical Session—Ballroom
12:30 P.M.– 5:30 P.M.	Trip No 2. General Electric Lamp Development Laboratories
5:00 P.M.	Close of registration and exhibition.
7:00 P.M.	Annual banquet and entertainment—Ballroom.

Wednesday—May 13

9:00 A.M.	Registration and opening of exhibition.
10:00 A.M.–12:30 P.M.	Technical Session—Ballroom
12:30 P.M.– 2:00 P.M.	Luncheon and inspection of exhibits.
2:00 P.M.– 4:30 P.M.	Technical Session—Ballroom
3:00 P.M.	Close of registration and exhibition.

PROCEEDINGS OF

The Institute of Radio Engineers

VOLUME 24 | May, 1936 | NUMBER 5

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PART II

Technical Papers

The Institute of Radio Engineers

GENERAL INFORMATION

INSTITUTE. The Institute of Radio Engineers was formed in 1912 through the amalgamation of the Society of Wireless Telegraph Engineers and the Wireless Institute. Its headquarters were established in New York City and the membership has grown from less than fifty members at the start to several thousand.

AIMS AND OBJECTS. The Institute functions solely to advance the theory and practice of radio and allied branches of engineering and of the related arts and sciences, their application to human needs, and the maintenance of a high professional standing among its members. Among the methods of accomplishing this is the publication of papers, discussions, and communications of interest to the membership.

PROCEEDINGS. The PROCEEDINGS is the official publication of the Institute and in it are published all of the papers, discussions, and communications received from the membership which are accepted for publication by the Board of Editors. Copies are sent without additional charge to all members of the Institute. The subscription price to nonmembers is $10.00 per year, with an additional charge for postage where such is necessary.

RESPONSIBILITY. It is understood that the statements and opinions given in the PROCEEDINGS are views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole. Papers submitted to the Institute for publication shall be regarded as no longer confidential.

REPRINTING PROCEEDINGS MATERIAL. The right to reprint portions or abstracts of the papers, discussions, or editorial notes in the PROCEEDINGS is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs published in the PROCEEDINGS may not be reproduced without making specific arrangements with the Institute through the Secretary.

MANUSCRIPTS. All manuscripts should be addressed to the Institute of Radio Engineers, 330 West 42nd Street, New York City. They will be examined by the Papers Committee and the Board of Editors to determine their suitability for publication in the PROCEEDINGS. Authors are advised as promptly as possible of the action taken, usually within two or three months. Manuscripts and illustrations will be destroyed immediately after publication of the paper unless the author requests their return. Information on the mechanical form in which manuscripts should be prepared may be obtained by addressing the secretary.

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	El Monte, 1001 N. Tyler St., Route 2	Clark, J. H.
	Inverness, Box 111	Yokela, H. E.
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	Los Angeles, 906 S. Shenandoah Ave.	Birlenbach, S.
	Los Angeles, 1607 S. Crescent Heights Blvd.	Brace, F. R.
	Oakland, 5715 Oak Grove Ave.	Aiello, J.
	Stanford University, P.O. Box 945	Kulikowski, E. F.
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	Brooklyn, 875 E. 21st St.	Mazyck, E. H.
	Coldwater, 245 Crestwood Blvd.	O'Brien, J. C.
	Flushing, 34-19 Murray St.	Hana, T. C.
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	New York, 106-7th Ave.	Greengard, J. E., Jr.
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	New York, 10 E. 40th St.	Ostrolenk, S.
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	Cleveland, 1311 Terminal Tower	Snedeker, M. L.
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	Narberth, 300 Essex Ave.	Bean, N. S.
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Tennessee	Chattanooga, American Lava Corp.	Thurnauer, H.
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Virginia	Quantico, 1st Signal Co., Marine Barracks	Kozakewicz, B. J.
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	Toronto 9, Ont., 82 Glendonwynne Rd.	Dean, H. B.
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	London S.W. 6, 6 Chesilton Rd., Fulham	Weale, D. A.
	North Farnborough, Hants., "Quetta," Ship Lane	Woods, C. H.
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Italy	Genova, Via Giordana Bruno 18	Monachesi, L.
	Milano, 4 Via S. Margherita	Ausenda, C.
Puerto Rico	San Juan, RCA Communications, Inc., Edificio Ochoa	General, J.
Scotland	Paisley, 9 Barclay St.	Thomson, W. B.
South Africa	Beaufort West, C. P., c/o Barclay's Bank Ltd.	Gibson, M.

Elected to the Junior Grade

Illinois	Chicago, 1725 Wilson Ave.	Manatt, J.
Pennsylvania	Emporium, c/o C. A. Gasperson, 5 E. 4th St.	Somers, O. M.
	Pittsburgh, 7137 McPherson Blvd.	Bensley, J. T.

Geographical Location of Members Elected

Elected to the Student Grade

California	Pasadena, 400 N. Holiston Ave.	Nestler, W. W.
Indiana	West Lafayette, Purdue Memorial Union	Lane, R. F.
Kansas	Lawrence, 1011 Indiana St.	Gemmill, F. Q.
Massachusetts	Cambridge, M.I.T. Dormitories	Kerr, D. E.
	West Somerville, 9 Lovell St.	Howard, S. B.
	Worcester, 25 Schussler Rd.	Libby, L. L.
Michigan	Ann Arbor, 630 Packard St.	Chapman, F. W.
	Houghton, 273 College Ave.	Bacon, C. W.
New Jersey	Newark, 288 Ridge St.	Brettell, G. A., Jr.
New York	Brooklyn, 77 Linden Blvd.	White, R. L.
	Ithaca, 207 Williams St.	Condren, J. M., Jr
Ohio	Cincinnati, 1248 Rutledge St., Price Hill	Brauer, H. H.
Oklahoma	Tulsa, 1227 S. Frisco Ave.	Griffith, B. W., III
Pennsylvania	Bethlehem, 612 Montclair Ave.	Bomberger, D. C.
	Philadelphia, 6814 McCallum St.	Weil, W. S., Jr.
England	London, S.W. 7. City and Guilds College, Exhibition Rd., South Kensington	Foot, G. H.
	London N.W. 10, 17 Park Ave., West Twyford	Mole, J. H.

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Admissions Committee. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before May 29, 1936. These applications will be considered by the Board of Directors at its meeting on June 3, 1936.

For Transfer to the Fellow Grade

New York	New York, Bell Tel. Labs., Inc., 463 West St.	Bailey, A.

For Transfer to the Member Grade

New Jersey	Teaneck, 431 Claremont Ave.	Shelby, R. E.
New York	New York, Bell Tel. Labs., Inc., 463 West St.	Bair, R. S.
	New York, Hazeltine Service Corp., 333 W. 52nd St.	Dean, C. E.
	New York, Bell Tel. Labs., Inc., 463 West St.	Green, E. I.
	New York, Bell Tel. Labs., Inc., 180 Varick St.	Morrison, J. F.
	New York, National Broadcasting Co., 30 Rockefeller Plaza	Schuetz, R. F.
	New York, Bell Tel. Labs., Inc., 180 Varick St.	Tinus, W. C.
Pennsylvania	Emporium, 115 E. 5th St.	Steen, J. R.
Texas	Galveston, 209 Prudential Bldg.	McCabe, L. L.
France	Clichy, Seine, 41 Allees Leon Gambetta	Lagasse, A. C.

For Election to the Member Grade

New York	Brooklyn, 80 Willoughby St.	Kurrelmeyer, B.
Australia	Sydney, N.S.W., c/o Stromberg-Carlson (Australasia) Ltd., 76 William St.	Bean, L. P. R.
Colombia	Bogota, Carrera 4a, No. 7151	Jaramillo, R.

For Election to the Associate Grade

California	Menlo Park, 125 Princeton Rd.	Kaar, J. M.
	San Francisco, 716 Masonic Ave.	Williams, P. A.
District of Columbia	Washington, Navy Department	Hull, D. R.
	Washington, 9-9th St. N.E.	Soukaras, K. M.
Georgia	Atlanta, 705 Piedmont Ave., N.E.	Parkins, F. A.
Idaho	Pocatello, 434 W. Bonneville	Wilson, T. J.
	Wallace, Fire Department	Heuser, E. R.
Illinois	Chicago, c/o RCA Institutes, 1154 Merchandise Mart	Hamm, J. L.
	Chicago, c/o RCA Institutes, 1154 Merchandise Mart	McMahon, R. J.
	Chicago, 5632 N. Meade Ave.	Thorson, W.
	Chicago, 1340 E. 48th St.	Wilson, D. M.
Indiana	Crown Point, Box 212	Murphy, E. J.
Kansas	Manhattan, Elec. Eng. Dept., Kansas State College	Schumann, F.
Maine	Bangor, 221 Center St.	Lawson, N. H.
Massachusetts	Boston, Northeastern Univ., 316 Huntington Ave.	Oberg, R. O.
	Foxboro, 5 Bassett St.	Ouimet, V. E.
Minnesota	Minneapolis, Elec. Eng. Dept., Univ. of Minnesota	Hartig, H. E.
New Jersey	Bloomfield, 84 Davis Ave.	Fuller, F. L.
	Camden, 715 Cooper St.	Johnson, L. R.
	Camden, 420 N. 2nd St.	Joyner, A. A.
	Camden, 109 N. 6th St.	Martin, K. H.
	Pleasantville, 311 W. Washington Ave.	Strockbine, J.
New York	New York, 310 W. 93rd St.	English, W. K.
	New York, Bell Tel. Labs., Inc., 463 West St.	Ingram, S. B.
	New York, Bell Tel. Labs., Inc., 180 Varick St.	Kuzela, E. V.
	New York, 1643 Clay Ave.	Waxler, B.
	Rego Park, L.I., 61-40 Saunders St.	Wilkens, W. B.
	Rochester, 50 Hopper Ter.	Sullivan, R. H.
	Rochester, Delco Appliance Corp.	Wallis, C. T.
	Schenectady, 1031 Helderberg Ave.	Williams, W. R.
	Scotia, 345 Glen Ave.	Beggs, J. E.
	Snyder, 75 Chateau Ter.	Osborne, F. H.
	Tonawanda, 48 Fremont St.	Bauer, H. G.
	Tonawanda, 369 Kohler St.	Best, T. A., Jr.
Ohio	Cleveland, USS Tahoma, C. G.	Jones, M. S.
	Cleveland, 7602 Home Ct.	Knife, W. J.
	Fairfield, 61 N. Main St.	Magee, E. E.
	Oxford, Oxford Radio Service	Damm, R. M.

Applications for Membership

Pennsylvania	Bethlehem, Elec. Eng. Dept., Lehigh Univ.	Formhals, W. H.
	Central City, U.S. Airways Station, R.F.D. 1	Sponeybarger, J. O.
Texas	San Antonio, 130 Belden Ave.	Dupree, J. E.
Wisconsin	Rhinelander, U.S. Forest Service	Alusic, J.
Australia	Ashfield, N.S.W., c/o Amalgamated Wireless (A'sia) Ltd., 554 Parramatta Rd.	Huey, R. M.
	Ashfield, N.S.W., A.W.A. Radio Electric Works	O'Donnell, A.
	Burwood, N.S.W., 51 Park Rd.	Freeman, A. C.
Canada	Toronto 4, Ont., 805 Davenport Rd.	Cumming, A. A.
England	Cricklewood, London N.W. 2, 112 Gladstone Park Gardens	Ellen, R. G.
	Dudley, Worcs., The Grove, Kingswinford	Herdman, T. L.
	Islington, London N. 1, Culford Works, Kingsbury Rd.	Andersen, R. C.
	Streatham, London, 63 Baldry Gardens	Harrison, K. W.
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Holland	Eindhoven, Bredalaan 77	Severs, J.
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	Yokkaiti, Mie-ken, Nihon Musen Yokkaiti Syuttyozyo	Miyakosi, K.
North Wales	Old Colwyn, "Headlands," Bryn Ave.	Oliver, C. J.
Norway	Oslo, Bjerregaardsgt. 29 E.	Flood, S. W.
South Africa	Durban, Natal, African Broadcasting Co. Ltd.	Heyes, O.
	Crecy P. O., N. Transvaal, c/o Captain P. C. Sanderson, "Belmont"	Houghton, H. W.

For Election to the Junior Grade

California	Glendale, 1529 Ridgeway Dr.	Tate, J. W.
Illinois	Chicago, 1401 E. 55th St.	Kealy, D.
	Chicago, 1142 W. Grand Ave.	Scaruffi, J.
	Evanston, 1225 Grant St.	Chalberg, H. W. A.

For Election to the Student Grade

Connecticut	New Haven, 25 Irving St.	Clements, S. E.
Massachusetts	Cambridge, M.I.T. Dormitories	Farmer, D. E.
	Cambridge, 273 Harvard St.	Hedberg, C.
	Cambridge, 66 Wendell St.	Mao, Y. Y.
Michigan	Ann Arbor, 1208 South University	Shannon, C. E.
Ohio	Columbus, 763 Mohawk St.	Fritschel, P. G.
Texas	Austin, Dept. of Physics, Univ. of Texas	Jones, H. W.
Canada	Edmonton, Alta., 10731-97th St.	Jordan, E. C.
England	London W. 12, 24 Shepherds Bush Green	Beebe, R. D.

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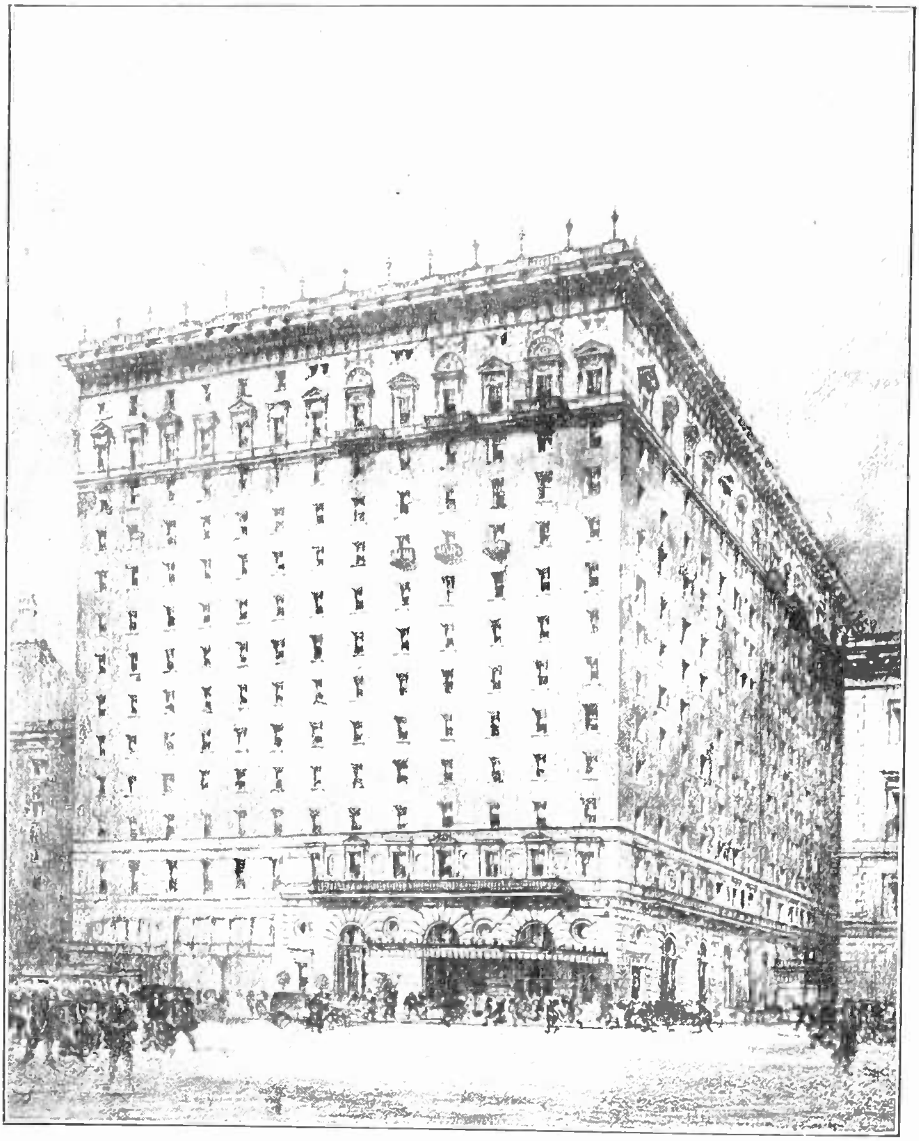


The Hotel Statler in Cleveland, Ohio, pictured above is the headquarters for our Eleventh Annual Convention.

INSTITUTE NEWS AND RADIO NOTES

Eleventh Annual Convention

An invitation from our Cleveland Section to hold the Eleventh Annual Convention of the Institute in that city was accepted by our Board of Directors and scheduled for May 11, 12, and 13, with headquarters at the Hotel Statler. Cleveland is centrally located in regard to the geographical distribution of Institute members in this country and Canada and is an overnight trip for most of those who will attend.

Located on the southern shore of Lake Erie, it has become a leading iron and steel center. Its ore is delivered by lake boats which are emptied by huge unloaders capable of picking up almost a carload at a time. Its coal comes from the fields of Ohio and Pennsylvania and the smelters of Cleveland have a capacity of about three million tons of pig iron annually. Among its twenty-five hundred manufacturing plants are represented at least two thirds of the nation's industries.

In 1795, what is now the public square which faces the Union Terminal was purchased for a dollar and seventy-six cents. The next year, Moses Cleaveland established his isolated trading post there because the site promised trading and commercial possibilities. A present-day price tag on the square would probably read in the order of twenty million dollars.

The program for our convention includes technical sessions, inspection trips, an exhibition, and a banquet. It has been arranged by the local convention committee and differs in some respects from the past few conventions.

A reduction in the number of inspection trips and a lengthening of some of the technical sessions permits the presentation of all technical papers without the necessity of simultaneous meetings. This will avoid the necessity of choosing between papers being given at the same time and the confusion surrounding the free movement of members between two technical sessions. It is anticipated that the following program will be changed only to a very minor degree if at all.

Those who can arrange to register on Sunday afternoon are urged to do so as this assists greatly in reducing the time required to complete registration on Monday morning just before the opening session.

SUNDAY, MAY 10

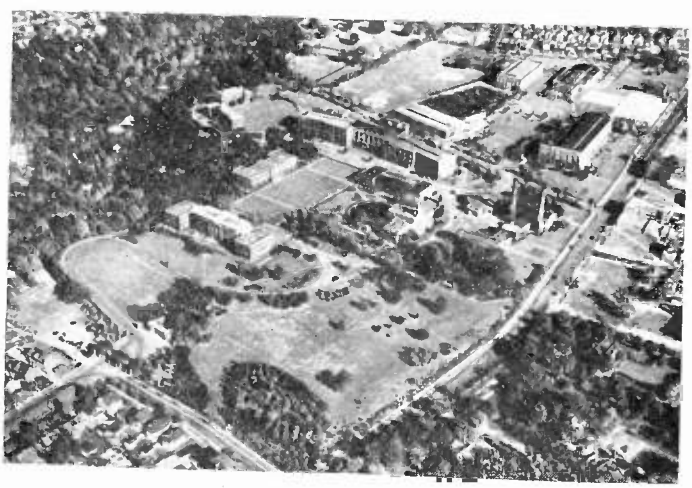
4:00 P.M.–6:00 P.M. Registration.

MONDAY, MAY 11

9:00 A.M. Registration and opening of exhibition.

Downtown Cleveland pictured from the air.

A view of Cleveland from the lake.



The General Electric group at Nela Park.

10:30 A.M.–12:30 P.M. Official welcome and technical session. Addresses of welcome by Alan Hazeltine, President of the Institute; R. M. Pierce, Chairman of the Cleveland Section; and K. J. Banfer, Chairman of the Convention Committee.

Technical Session—Ballroom

"High Speed Motion Pictures of Mercury-Vapor Tube Operation," by H. W. Lord, General Electric Company, Schenectady, N.Y.

"Radio Transmission Anomalies," by J. H. Dellinger, S. S. Kirby, and N. Smith, National Bureau of Standards, Washington, D.C.

"Recent Investigations of the Ionosphere", by S. S. Kirby and N. Smith, National Bureau of Standards, Washington, D. C.

10:30 A.M.–1:00 P.M. Ladies meet in Parlor 1.

12:30 P.M.–2:00 P.M. Luncheon and inspection of exhibits.

1:00 P.M. Trip No. 1. Ladies luncheon and visit to the Higbee Department Store and WHK Studios.

2:00 P.M.–4:15 P.M. **Technical Session—Ballroom**

"Ultra-High-Frequency High Power Transmitter Using Short Transmission Lines," by John Evans, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

"A Modern Two-Way Radio System," by Stewart Becker and L. M. Leeds, General Electric Company, Schenectady, N.Y.

"A Multitube Ultra-High-Frequency Oscillator," by P. D. Zottu, RCA Manufacturing Company, RCA Radiotron Division, Harrison, N.J.

6:00 P.M. Close of registration and exhibition.

TUESDAY, MAY 12

9:00 A.M. Registration and opening of exhibition.

10:00 A.M.–12 noon **Technical Session—Ballroom**

"The Effect of Automatic Volume Control Upon the Measurement of Selectivity of Radio Receivers," by D. S. Bond, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

"Automatic Tuning—Simplified Circuits and Design Practice," by D. E. Foster and S. W. Seeley, RCA License Laboratory, New York, N.Y.

"Aural Compensation," by C. M. Sinnett, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

12:30 P.M.–5:30 P.M. Trip No. 2. General Electric Lamp Development Laboratories.

5:00 P.M. Close of registration and exhibition.

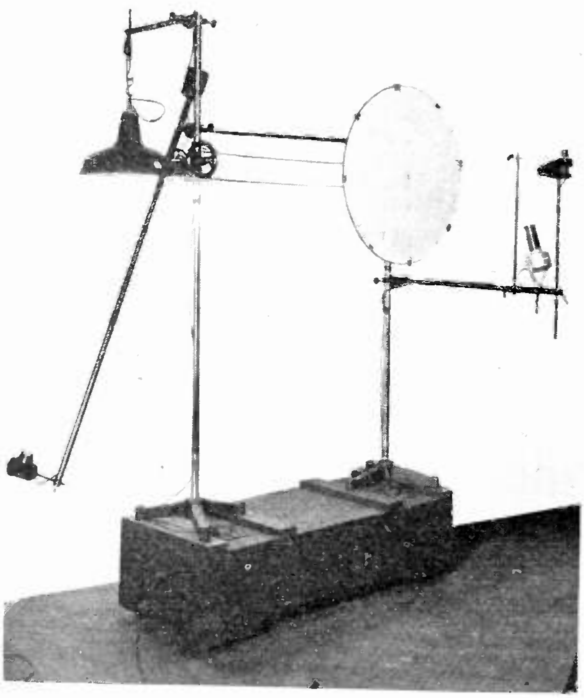
7:00 P.M. Annual banquet and entertainment—Ballroom.

WEDNESDAY, MAY 13

9:00 A.M. Registration and opening of exhibition.

10:00 A.M.–12:30 P.M. **Technical Session—Ballroom**

Dry-disk photocell quadrant reflectometer.



Distribution analyzer for lighting units.

"A New High Efficiency Power Amplifier for Modulated Waves," by W. H. Doherty, Bell Telephone Laboratories New York, N.Y.

"Simplified Methods for Computing Performance of Transmitting Tubes," by W. G. Wagener, RCA Manufacturing Company, RCA Radiotron Division, Harrison, N.J.

"The 'Shunt Excited' Antenna," by J. F. Morrison and P. H. Smith, Bell Telephone Laboratories, New York, N.Y.

"Some Notes on Amplifier Transients," by C. W. Carnahan, Hygrade Sylvania Corporation, Salem, Mass.

12:30 P.M.–2:00 P.M. Luncheon and inspection of exhibits.

2:00 P.M.–4:30 P.M. Technical Session—Ballroom

"Electron Optics of Television Cathode-Ray Tubes," by D. W. Epstein, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

"A Cathode-Ray Time Axis for High Frequency," by L. M. Leeds, General Electric Company, Schenectady, N.Y.

"Application of Conventional Vacuum Tubes in Unconventional Circuits," by F. H. Shepard, Jr., RCA Manufacturing Company, RCA Radiotron Division, Harrison, N.J.

"A Study of Noise Characteristics," by V. D. Landon, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

"Cathode-Ray Oscillograph Applications Other than Radio," by H. J. Schrader, RCA Manufacturing Company, RCA Victor Division, Camden, N.J.

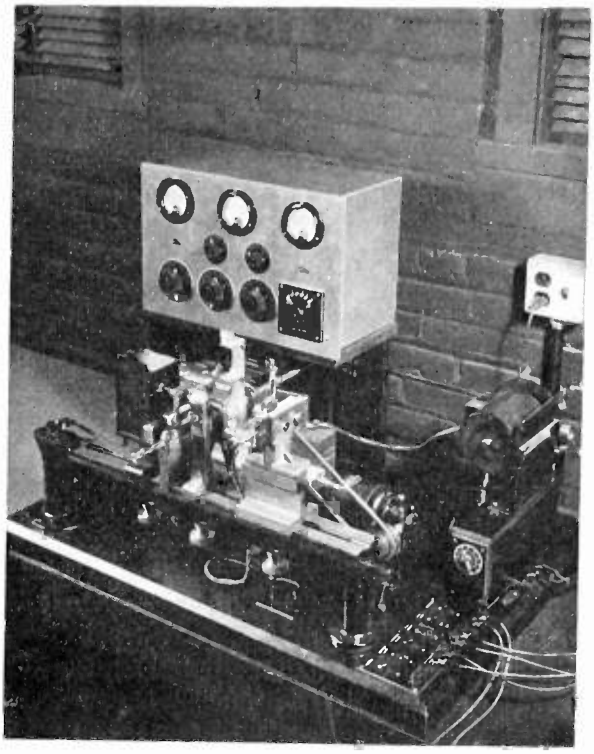
"A Potentiometric Direct-Current Amplifier and its Applications," by R. W. Gilbert, Weston Electrical Instrument Corporation, Newark, N.J.

3:00 P.M. Close of registration and exhibition.

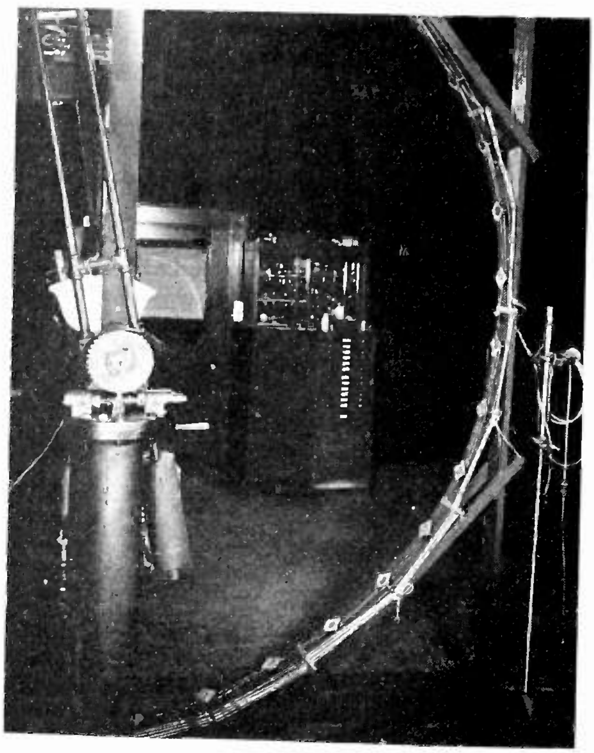
Technical Sessions

None of the papers which are scheduled for presentation at the five technical sessions will be available in preprint form. While attempts will be made to obtain all these papers for publication in the PROCEEDINGS, it highly probable that there will be several which will not appear therein. There will be no duplication of the technical sessions and the program is so arranged as to permit those in attendance to hear all papers in which they are interested.

Sufficient time has been allotted to each paper to permits its presentation substantially in full. This should permit as active discussion of



Analyzer for sound recording and reproducing optical systems.



Dry-disk photoelectromotive-force cell integrating photometer.

each paper as its contents dictate. Such discussions are of substantial benefit to everyone in attendance and are the prime reason for the oral presentation of papers. Everyone is urged to participate in these discussions. Summaries of all papers are given in this issue.

Inspection Trips

Monday, May 11—Trip No. 1

Ladies Visit to Higbee Department Store and WHK.

Busses will leave the hotel promptly at 1:00 P.M. for the Higbee Department Store where a luncheon will be served followed by an entertaining program. This program will include a style demonstration.

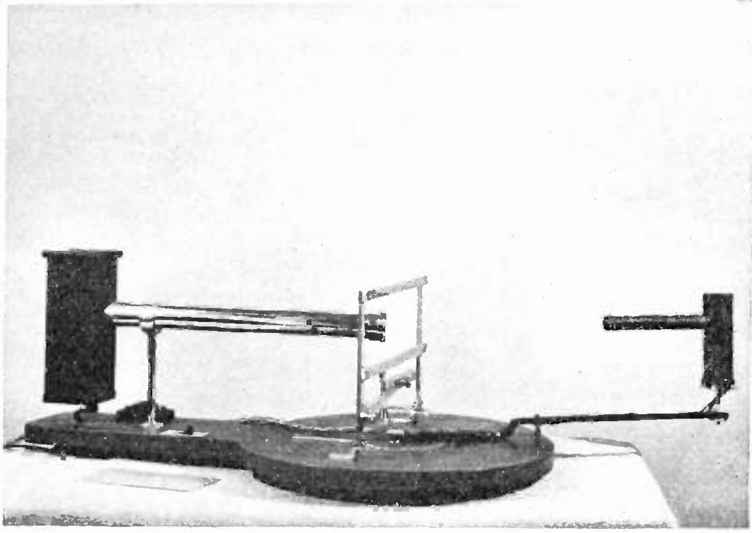
Union Terminal Building housing the Higbee Store and WHK Studios.

At its conclusion, the studios of Broadcast Station WHK will be visited. They are located in the Terminal Tower Building which houses the Higbee Department Store as well. This trip is made possible through the generosity of the Ohio Carbon Company.

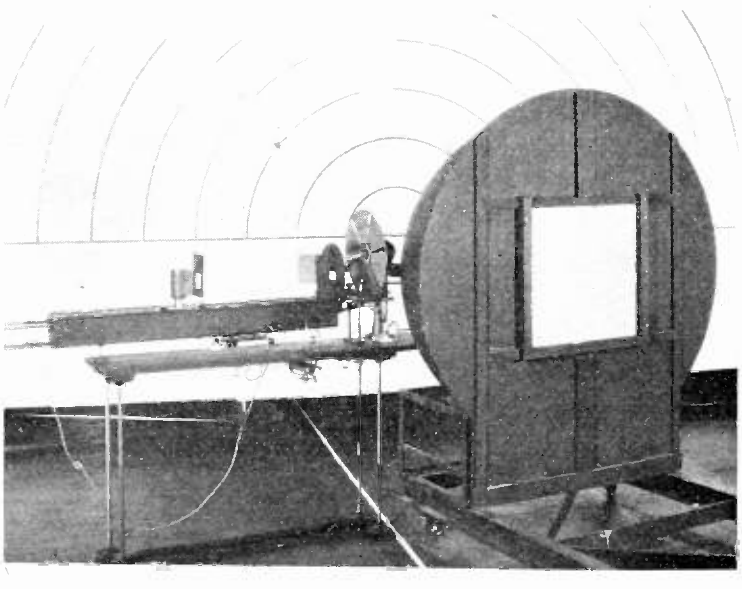
Tuesday, May 12—Trip No. 2

General Electric Lamp Development Laboratories

Promptly at 12:30 P.M. busses will leave the hotel for Nela Park in which the General Electric Company Lamp Development Laboratories



Photoelectric photometer for measuring the diffusion of glass.



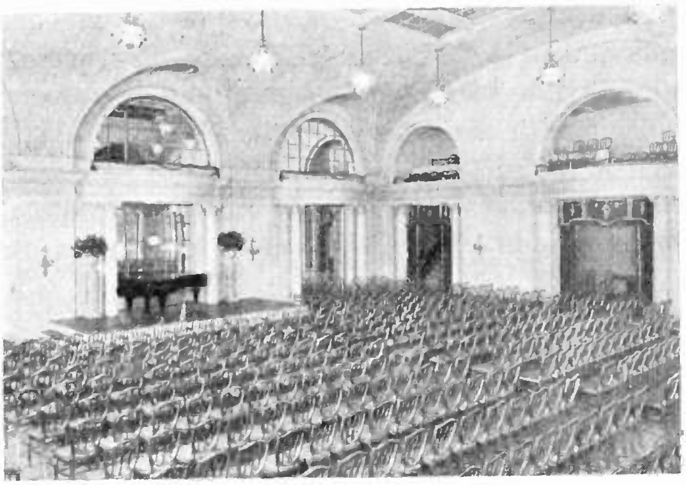
Hemisphere integrators for lumen distribution from flood-lighting projectors.

are located. The General Electric Company will be our hosts at a luncheon which will be served at 1:30 P.M. The ladies are especially invited to attend this trip. Special entertainment has been arranged for them and demonstrations will be given at the General Electric Institute in beautifying and adding to the comfort of the home.

The men will visit the Engineering and Lamp Development Laboratories, the General Electric Institute, and the Division of Household Appliances. The tour will include lectures, demonstrations, motion pictures, and a dramatization of the magic of modern electrical application.

Ladies' Special Trips

It is anticipated that many of the ladies in attendance may desire to take special trips which might not be suitable for or of interest to the entire group. Time has been provided in the schedule to permit such



Ballroom of the Hotel Statler.

activities and the Ladies' Committee is prepared to provide for such trips and supply guides where they may be of assistance. Full information will be available at the ladies' headquarters in Parlor 1.

Exhibition

The exhibition which has been a part of these conventions for the past several years will bring the latest developments in the manufacturing and laboratory fields to the attention of those present. The booths will be distributed throughout the foyers which surround the meeting room. Booths will be in charge of men who are competent to discuss engineering aspects of the products displayed. Ample time has

been provided in the program to permit a complete inspection to be made of all booths in which the member may be interested.

Banquet

Our annual banquet will be held in the ballroom at seven o'clock on Tuesday evening. During it, the Institute Medal of Honor will be presented to George A. Campbell for his contributions to the theory of electrical networks. The recipient of the Morris Liebmann Memorial Prize has not yet been announced but the award will be made at the banquet. A program of entertainment has been arranged and those who are interested in attending the banquet are urged to make early reservations as the seating facilities are not unlimited.

Sections Committee Meeting

The annual meeting of the Sections Committee will be held at 4:30 P.M. on Monday, May 11, in Parlor K. It is the duty of each section to be represented at this meeting. If the chairman or secretary-treasurer of the section cannot be in attendance, it is advisable to designate some other member of the section who can attend to represent it. At this meeting, those problems which face all sections are discussed as are proposals for changes in existing methods of handling section matters.

Reduced Railroad Rates

Reduced railroad rates on the certificate plan have been granted and require the purchase of regular one-way first-class tickets for the journey to Cleveland between May 7 and 13 for the Central and Eastern portions of the country. In the more remote sections such as the Southwest and West, tickets are available as early as May 3. When purchasing tickets, a certificate for this convention should be requested and signed. On arrival at the convention, deposit your certificate at the registration desk and if and when one hundred such certificates are received, they will be validated and permit the purchase of a return trip ticket over the same route traveled in the journey to Cleveland at one-third of the regular first-class fare. Return tickets are good for return passage to reach the original starting point within thirty days in addition to the date of sale of the going ticket.

SUMMARIES OF TECHNICAL PAPERS

A MODERN TWO-WAY RADIO SYSTEM

STEWART BECKER AND L. M. LEEDS
(General Electric Company, Schenectady, N.Y.)

The general problems and limitations encountered in two-way police communication are discussed. A unique receiver circuit especially adapted to the adverse conditions imposed upon this class of equipment is described in detail and performance curves are shown. Several transmitters are described and their salient features pointed out. A new type ultra-high-frequency antenna system is disclosed and its general theory of operation explained.

THE EFFECT OF AUTOMATIC VOLUME CONTROL UPON THE MEASUREMENT OF SELECTIVITY OF RADIO RECEIVERS

DONALD S. BOND
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

Several basic automatic gain control circuits are analyzed for selectivity measurements by the constant-signal-input and the constant-output methods. In a self-controlled system (all selectivity preceding the automatic volume control point) "true" selectivity may be measured with no automatic volume control or by the constant-output method. In a parallel-channel system, on the other hand, true selectivity can be measured directly with no automatic volume control. The results obtained with constant-signal-input and constant-output are discussed, as well as the effect of adjacent-channel signal fading. Selective circuits and controlled-loss amplifiers may be grouped to reduce more complicated cases to the fundamental ones described.

SOME NOTES ON AMPLIFIER TRANSIENTS

C. W. CARNAHAN
(Hygrade Sylvania Corporation, Salem, Mass.)

Approximate methods are developed for obtaining the transient behavior of complex networks, such as multistage amplifiers. The indicial response of the network is approximated by a Fourier series which is the response to a periodic rectangular driving force, the period of which is made great enough for the network response to approach its steady value by the end of one half period. The advantages of this method of solution in ease of computation and in correlating the steady-state characteristics with the transient behavior, are pointed out. A method for obtaining the time constant of the network from an analysis of its steady-state characteristics is also shown. Typical television amplifiers are taken for examples of the use of these methods. Radio-frequency amplifiers are treated briefly.

RADIO TRANSMISSION ANOMALIES

J. H. DELLINGER, S. S. KIRBY, AND N. SMITH
(National Bureau of Standards, Washington, D.C.)

Two types of interruptions in high-frequency radio transmission have recently been observed. One type, a sudden and short-time interruption of the intermediate high-frequency transmission over the daylight side of the globe, is caused apparently by a temporary excessive absorption in the lower ionosphere. Evidence indicates that an eruptive prominence appears on the sun at the time of each of these fade-outs. The other type of disturbance, a lowering of the maxi-

mum useful frequency for communication, is more protracted and is caused by a decrease in the maximum ionization density in the F_2 region of the ionosphere, accompanied by an increase in the virtual height of this region. This type of disturbance occurs both during the day and at night, and is associated with low sunspot activity and severe magnetic disturbances.

Measurements on the field strengths of various European and South American broadcast stations during the last winter have shown definitely that transmission to Washington over the North Atlantic path is about five per cent as efficient as that over paths in the continental United States and to South America in the case of frequencies between 500 and 1300 kilocycles.

A NEW HIGH EFFICIENCY POWER AMPLIFIER FOR MODULATED WAVES

W. H. Doherty
(Bell Telephone Laboratories, New York City)

This paper introduces a new form of linear power amplifier for modulated radio-frequency waves. Plate circuit efficiencies of sixty to sixty-five per cent independent of modulation are obtained by means of the combined action of varying load distribution among the tubes and varying circuit impedance over the modulation cycle.

The theory of operation is developed and detailed observations on the behavior of tubes in the new circuit are given in the paper. The use of stabilized feedback in connection with this circuit is discussed and significant measurements on a laboratory model of a fifty-kilowatt amplifier are shown.

ELECTRON OPTICS OF TELEVISION CATHODE-RAY TUBES

D. W. Epstein
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

The electron beam of a television cathode-ray tube is focused by means of an electron optical system of two coaxial cylinders. This paper presents a treatment of such a focusing system.

Theoretical curves are presented giving the optical constants of the lenses equivalent to two coaxial cylinders of various diameters and at various voltages. The use of these optical constants in the design of cathode-ray tubes is then illustrated by means of a simple example.

A method of measuring these optical constants is briefly described and the results obtained experimentally are compared with the theoretical curves.

The approximation involved in substituting thin lenses for the actual thick lenses is discussed and a simple method for the experimental determination of the location and focal lengths of the thin lens is given.

It is then shown that in a well-designed and well-constructed tube, spherical aberration is the only aberration damaging the spot size. The effect of spherical aberration on the spot size is then described and the amount of spherical aberration present in electrostatic lenses due to two cylinders is given.

ULTRA-HIGH-FREQUENCY HIGH POWER TRANSMITTER USING SHORT TRANSMISSION LINES

John Evans
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

In this paper is discussed an ultra-high-frequency transmitter in the frequency range of forty to sixty megacycles with a final amplifier using AW-200 vacuum tubes, having a useful power output of approximately forty kilowatts

for the class C condition of operation. The frequency stability is in the order of 0.001 per cent for changes of anode voltage of twenty per cent and for changes of ambient of positive forty degrees centigrade and for filament voltage variations of five per cent without recourse to the use of piezoelectric devices. The stabilizing of frequency is accomplished by the use of refined circuits involving short transmission lines. The circuits of the intermediate amplifier stages also comprise transmission lines. Mention is also made of methods used to prevent the generation of spurious oscillations in the oscillator particularly and amplifier circuits. Also discussed is the method used for providing phase stabilizing of the oscillator by using degenerative phasing means common to the oscillator's associated circuits. The oscillator for simplicity is of the single ended type, necessitating a special method of coupling to the intermediate amplifier, which is also described. Variation of the quantity Q against oscillator loading is mentioned. This research and development was conceived and completed in order to determine what could be accomplished by using existing, commercially available tubes. A method of providing a source of constant frequency for measurement purposes surpassing that of piezoelectric crystals is also described.

AUTOMATIC TUNING—SIMPLIFIED CIRCUITS AND DESIGN PRACTICE

D. E. Foster and S. W. Seeley
(RCA License Laboratory, New York, N.Y.)

Within the last twelve months automatic tuning control circuits have been much simplified. The principles underlying automatic frequency control of the oscillator in superheterodyne receivers have been outlined in previous papers given before the I.R.E. This paper deals with simplification and improvements in operation of frequency control circuits and their application to automatic (electronic) tuning control.

A new type of "discriminator" which differentiates between mis-tuned signals on the high-frequency side of resonance and those on the low-frequency side is described and its operation demonstrated by means of a visual frequency indicator.

The operation of the discriminator is such that it may be used to supply audio-frequency components corresponding to the amplitude modulations of the received carrier wave and automatic volume control potentials as well as the control voltage for the frequency control circuits. This multifunction is described and illustrated.

Alternative circuit connections to improve the compromise between discriminator sensitivity, audio fidelity, and selectivity are explained and illustrated.

The use of vacuum tubes in such manner that they act as reactive components and the manner in which their apparent reactive impedance may be controlled by varying the tube parameters is demonstrated.

The action of a complete receiver embodying automatic (electronic) tuning control in overcoming mis-tuning and oscillator frequency drift will be demonstrated.

A POTENTIOMETRIC DIRECT-CURRENT AMPLIFIER AND ITS APPLICATIONS

R. W. Gilbert
(Weston Electrical Instrument Corporation, Newark, N.J.)

This instrument presents a method of direct-current amplification wherein the output is maintained in a null potentiometric relationship to the input by

means of an electronic balancing mechanism. In this way complete independence from the effects of the nonlinear and variable electronic devices upon stability and calibration is obtained.

A speed greater than that of most indicating instruments is attained, and operation of the null galvanometer under ideal conditions allows a high degree of sensitivity. The instrument is operated entirely from service power, and is capable of driving high speed recorders, rugged indicating instruments, relays, etc., calibrated in terms of an input normally far below the range of such devices.

RECENT INVESTIGATIONS OF THE IONOSPHERE

S. S. Kirby and N. Smith
(National Bureau of Standards, Washington, D.C.)

Virtual heights and critical frequencies of the ionosphere have been measured one or more days each week at Washington principally at frequencies above 4500 kilocycles. Monthly averages of hourly values of virtual heights and critical frequencies are plotted to show the average diurnal variation for each month from November, 1934, to date. Annual and long-time variations are shown for certain hours of the day. In general during the summer day the critical frequency of the F_2 region is low and its virtual height high while during the summer evening and the winter day the opposite is true. Results over several years indicate that the critical frequency is increasing with the advance of the eleven-year sunspot cycle. Correlations with short-time sunspot cycles are also shown.

A STUDY OF NOISE CHARACTERISTICS

V. D. Landon
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

It is well known that when smooth noise, such as hiss, is passed through, or generated in, a radio-frequency amplifier, the root-mean-square output is proportional to the square root of the frequency band width. Experiments are described which show that the peak value of the hiss is also proportional to the square root of band width. The crest factor (defined as the ratio of the amplitudes of the highest peaks to the root-mean-square value) was found to be equal to 3.4 and independent of band width.

When the noise is due to impulse excitation (with decay trains not overlapping) the result is quite different. The root-mean-square amplitude is still proportional to the square root of frequency band passed. However, the peak amplitudes are directly proportional to the first power of the frequency band. This result is verified mathematically and experimentally.

A CATHODE-RAY TIME AXIS FOR HIGH FREQUENCY

Laurence M. Leeds
(General Electric Company, Schenectady, N.Y.)

A periodically recurrent high-frequency time axis generator with return trace removal is described. The theoretical nonlinearity is less than one per cent. The apparatus is capable of tracing out one cycle of a thirty-megacycle wave. The wave form of a conventional high-frequency oscillator is altered by means of a high vacuum rectifier circuit to obtain the required sweep voltage wave. Return trace removal is accomplished by biasing the control grid of the cathode-ray tube to cutoff over the return trace portion of the sweep cycle.

HIGH SPEED MOTION PICTURES OF MERCURY-VAPOR TUBE OPERATION

H. W. Lord
(General Electric Company, Schenectady, N.Y.)

These motion pictures were taken with a high speed camera and are of the arc spot in mercury-vapor tubes. Taken under conditions of overload and arc-back, they show some little suspected phenomenon in connection with the motion of the cathode spot over the surface of the mercury.

THE "SHUNT EXCITED" ANTENNA

J. F. Morrison and P. H. Smith
(Bell Telephone Laboratories, New York City)

The paper describes a novel arrangement for operating the vertical radiator type of broadcast antenna with the base grounded. Construction economy results through the elimination of the base insulator, the tower lighting chokes and the usual lightning protective devices. The coupling apparatus at the antenna end of the transmission line is reduced to an extent which may make unnecessary a separate building for its protection. Greater freedom from interruptions resulting from static charges is expected. The performance of the design is substantially the same as that obtained from the antennas now in general use.

The paper describes experimental work done and results obtained and inferences to be drawn from them. A mathematical appendix is attached.

CATHODE-RAY OSCILLOGRAPH APPLICATIONS OTHER THAN RADIO

H. J. Schrader
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

Using a cathode-ray oscilloscope and properly designed transducers it was found possible to simplify many measurements previously solved by purely mechanical testing equipment.

The oscillograph used in the solution of these measurement problems consists of a cathode-ray tube, a horizontal and a vertical amplifier, each with a wide frequency range, and a saw-tooth timing oscillator.

A piezoelectric transducer is used for the conversion of mechanical vibrations into electrical pulses which may than be applied to the oscillograph and their amplitude and frequency measured.

Alternators of a very simple design are employed in the measurement of torque and torsional vibration. The phase relationship of the output voltage of the two alternators is a measure of the twist of a power transmitting shaft and the rate of variation of the sum of these two voltages is a measure of any torsional vibration present.

A piezoelectric transducer is employed for the conversion of a pressure wave into a varying voltage and this voltage, after being amplified, causes a vertical deflection of the cathode-ray tube proportional to pressure. By means of a simple alternator and a contactor, both contained in one unit, and mechanically connected to the compressor or internal combustion engine it is possible to synchronize the pressure wave pictured on the tube screen and indicate "top dead center" or other wanted crank position.

APPLICATION OF CONVENTIONAL VACUUM TUBES IN UNCONVENTIONAL CIRCUITS

F. H. Shepard, Jr.
(RCA Manufacturing Company, RCA Radiotron Division, Harrison, N.J.)

This paper describes some out-of-the-ordinary yet simple and interesting vacuum tube applications. It illustrates how conventional vacuum tubes can be used in circuits which impose unusual requirements for grid current, noise, and life. Analysis of circuit requirements and knowledge of tube performance characteristics frequently make possible adjustment of operating conditions to give the desired results. The following demonstrations indicate the practicability of this procedure. They are also used to illustrate simple and logical methods of analyzing circuit operation.

(1) A two-stage photo amplifier relay circuit operating directly on the alternating-current line and using only two resistors and three condensors as circuit parts.

(2) A sensitive photo amplifier circuit using a pentode as a load resistor for the phototube, a standard tube as a relay, and a sensitive electrometer tube feeding a low priced indicating instrument.

(3) A simple vacuum tube circuit in which standard unselected tubes can be used to multiply currents in the order of 10^{-12} amperes by a definite factor (fixed by the circuit elements and not by the tube) to such values as can be easily read on an insensitive milliameter.

(4) A simple capacity-operated relay working on the alternating-current line using metal tubes and only a few inexpensive circuit parts.

AURAL COMPENSATION

C. M. Sinnett
(RCA Manufacturing Company, RCA Victor Division, Camden, N.J.)

In sound reproduction two factors contribute greatly to pleasing tone quality: aural compensation and volume expansion. The former recognizes the change in characteristic of the human ear at different volume levels and properly adjusts the low- and high-frequency balance to compensate. Volume expansion provides a means of restoring the dynamic range of symphonic music which has been compressed by monitoring so that it can be transmitted over a broadcast station or recorded on a phonograph record.

The audio discriminator is a laboratory tool for use with the above in determining the desired acoustic balance. This device by means of variable-gain band filters permits raising or lowering the response of different frequency bands over a range from thirty to 9000 cycles. Peaked, flat, or depressed response may be obtained at practically any point in the frequency scale. As a result, the electrical fidelity curve necessary to give this performance in the final instrument can be determined much quicker and more accurately than by ordinary cut-and-try methods.

SIMPLIFIED METHODS FOR COMPUTING PERFORMANCE OF TRANSMITTING TUBES

W. G. Wagener
(RCA Manufacturing Company, RCA Radiotron Division, Harrison, N.J.)

Simplified methods are given for quickly computing with reasonable accuracy the performance of transmitting tubes in the usual radio-frequency and audio-

frequency applications. More exact methods making full use of tube characteristic curves are also indicated.

The simplified methods are illustrated by calculations on a standard tube. These sample calculations covering the class C radio-frequency power amplifier, both telegraphy and plate modulated telephony, the class B radio-frequency linear power amplifier, the grid modulated radio-frequency power amplifier, and the class B audio-frequency power amplifier demonstrate the inherent capability of any tube in power amplifier service.

A MULTITUBE ULTRA-HIGH-FREQUENCY OSCILLATOR

P. D. Zottu
(RCA Manufacturing Company, Radiotron Division, Harrison, N.J.)

Two or more independent oscillators of approximately the same frequency are coupled to a common low-loss, quarter-wave concentric line circuit. The reaction between the low-loss circuit and the oscillators is such as to pull the oscillators into step. Using six type-834 tubes with 400 volts on the plates, a total output of fifty-four watts was obtained with an efficiency of twenty per cent, the operating wavelength being 120 centimeters. This efficiency is the same as that obtained from two type-834 tubes operating in the conventional push-pull arrangement at the same wave length. The system appears capable of considerable extension.

Proceedings of the Institute of Radio Engineers
Volume 24, Number 5 *May, 1936*

TECHNICAL PAPERS

A METHOD OF REDUCING DISTURBANCES IN RADIO SIGNALING BY A SYSTEM OF FREQUENCY MODULATION*

BY

EDWIN H. ARMSTRONG

(Department of Electrical Engineering, Columbia University, New York City)

Summary—*A new method of reducing the effects of all kinds of disturbances is described. The transmitting and receiving arrangements of the system, which makes use of frequency modulation, are shown in detail. The theory of the process by which noise reduction is obtained is discussed and an account is given of the practical realization of it in transmissions during the past year from the National Broadcasting Company's experimental station on the Empire State Building in New York City to Westhampton, Long Island, and Haddonfield, New Jersey. Finally, methods of multiplexing and the results obtained in these tests are reported.*

PART I

IT IS the purpose of this paper to describe some recent developments in the art of transmitting and receiving intelligence by the modulation of the frequency of the transmitted wave. It is the further purpose of the paper to describe a new method of reducing interference in radio signaling and to show how these developments may be utilized to produce a very great reduction in the effects of the various disturbances to which radio signaling is subject.

HISTORICAL

The subject of frequency modulation is a very old one. While there are some vague suggestions of an earlier date, it appears to have had its origin shortly after the invention of the Poulsen arc, when the inability to key the arc in accordance with the practice of the spark transmitter forced a new method of modulation into existence. The expedient of signaling (telegraphically) by altering the frequency of the transmitter and utilizing the selectivity of the receiver to separate the signaling wave from the idle wave led to the proposal to apply the principle to telephony. It was proposed to effect this at the transmitter by varying the wave length in accordance with the modulations of the voice, and the proposals ranged from the use of an electrostatic micro-

* Decimal classification: R400×R430. Original manuscript received by the Institute, January 15, 1936. Presented before New York meeting, November 6, 1935.

phone associated with the oscillating circuit to the use of an inductance therein whose value could be controlled by some electromagnetic means. At the receiver it was proposed to cause the variations in frequency of the received wave to create amplitude variations by the use of mistuned receiving circuits so that as the incoming variable frequency current came closer into or receded farther from the resonant frequency of the receiver circuits, the amplitude of the currents therein would be correspondingly varied and so could be detected by the usual rectifying means. No practical success came from these proposals and amplitude modulation remained the accepted method of modulating the arc. The various arrangements which were tried will be found in the patent records of the times and subsequently in some of the leading textbooks.[1] The textbooks testify unanimously to the superiority of amplitude modulation.

Some time after the introduction of the vacuum tube oscillator attempts were again made to modulate the frequency and again the verdict of the art was rendered against the method. A new element however, had entered into the objective of the experiments. The quantitative relation between the width of the band of frequencies required in amplitude modulation and the frequency of the modulating current being now well understood, it was proposed to narrow this band by the use of frequency modulation in which the deviation of the frequency was to be held below some low limit; for example, a fraction of the highest frequency of the modulating current. By this means an economy in the use of the frequency spectrum was to be obtained. The fallacy of this was exposed by Carson[2] in 1922 in the first mathematical treatment of the problem, wherein it was shown that the width of the band required was at least double the value of the highest modulating frequency. The subject of frequency modulation seemed forever closed with Carson's final judgment, rendered after a thorough consideration of the matter, that "Consequently this method of modulation inherently distorts without any compensating advantages whatsoever."

Following Carson a number of years later the subject was again examined in a number of mathematical treatments by writers whose results concerning the width of the band which was required confirmed those arrived at by Carson, and whose conclusions, when any were expressed, were uniformly adverse to frequency modulation.

[1] Zenneck, "Lehrbuch der drahtlosen Telegraphy," (1912).
Eccles, "Wireless Telegraphy and Telephony," (1916).
Goldsmith, "Radio Telephony," (1918).

[2] "Notes on the theory of modulation," Proc. I.R.E., vol. 10, pp. 57–82; February, (1922).

In 1929 Roder[3] confirmed the results of Carson and commented adversely on the use of frequency modulation.

In 1930 van der Pol[4] treated the subject and reduced his results to an excellent form for use by the engineer. He drew no conclusions regarding the utility of the method.

In 1931, in a mathematical treatment of amplitude, phase, and frequency modulation, taking into account the practical aspect of the increase of efficiency at the transmitter which is possible when the frequency is modulated, Roder[5] concluded that the advantages gained over amplitude modulation at that point were lost in the receiver.

In 1932 Andrew[6] compared the effectiveness of receivers for frequency modulated signals with amplitude modulated ones and arrived at the conclusion that with the tuned circuit method of translating the variations in frequency into amplitude variations, the frequency modulated signal produced less than one tenth the power of one which was amplitude modulated.

While the consensus based on academic treatment of the problem is thus heavily against the use of frequency modulation it is to the field of practical application that one must go to realize the full extent of the difficulties peculiar to this type of signaling.

Problems Involved

The conditions which must be fulfilled to place a frequency modulation system upon a comparative basis with an amplitude modulated one are the following:

1. It is essential that the frequency deviation shall be about a fixed point. That is, during modulation there shall be a symmetrical change in frequency with respect to this point and over periods of time there shall be no drift from it.

2. The frequency deviation of the transmitted wave should be independent of the frequency of the modulating current and directly proportional to the amplitude of that current.

3. The receiving system must have such characteristics that it responds only to changes in frequency and that for the maximum change of frequency at the transmitter (full modulation) the selective characteristic of the system responsive to frequency changes shall be such that substantially complete modulation of the current therein will be produced.

[3] "Ueber Frequenzmodulation," *Telefunken-Zeitung* no. 53, p. 48, (1929).
[4] "Frequency modulation," Proc. I.R.E., vol. 18, pp. 1194–1205; July, (1930).
[5] "Amplitude, phase, and frequency modulation," Proc. I.R.E., vol. 19, pp. 2145–2176; December, (1931).
[6] "The reception of frequency modulated radio signals," Proc. I.R.E., vol. 20, pp. 835–840; May, (1932).

4. The amplitude of the rectified or detected current should be directly proportional to the change in frequency of the transmitted wave and independent of the rate of change thereof.

5. All the foregoing operations should be carried out by the use of aperiodic means.

The Transmitting System

An extensive experience with the various known methods of modulating the frequency convinced the writer as indeed it would anyone who has tried to work with this method of modulation at a high frequency that some new system must be evolved. During the course of this work there was evolved a method which, it is believed, is a complete solution of the transmitter problem. It consists in employing the modulating current to shift the phase of a current derived from a source of fixed phase and frequency by an amount which is directly proportional to the amplitude of the modulating current and inversely proportional to its frequency. The resulting phase shift is then put through a sufficient number of frequency multiplications to insure 100 per cent modulation for the highest frequency of the modulating current. By keeping the initial phase shift below thirty degrees substantial linearity can be obtained.

The means employed to produce the phase shift consisted of a source of fixed frequency, a balanced modulator excited by this source, and arrangements for selecting the side frequencies from the modulator output and combining them in the proper phase with an unmodulated current derived from the initial source. The phase relations which must exist where the combination of the modulated and unmodulated currents takes place are that at the moment the upper and lower side frequencies produced by the balanced modulator are in phase with each other, the phase of the current of the master oscillator frequency with which they are combined shall differ therefrom by ninety degrees.

The schematic and diagrammatic arrangements of the circuits may be visualized by reference to Figs. 1 and 2, and their operation understood from the following explanation. The master oscillator shown in these diagrams may be of the order of fifty to one hundred thousand or more cycles per second, depending upon the frequency of the modulating current. An electromotive force derived from this oscillator is applied in like phase to the grid of an amplifier and both grids of a balanced modulator. The plate circuits of the modulator tubes are made nonreactive for the frequency applied to their grids by balancing out the reactance of the transformer primaries as shown. The plate cur-

rents are therefore in phase with the electromotive force applied to the grid. The succeeding amplifier is coupled to the output transformer by a coil whose natural period is high compared to the frequency of the master oscillator and the electromotive force applied to the grid of this amplifier when the modulator tubes are unbalanced by a modulating voltage applied to the screen grids is therefore shifted in phase ninety

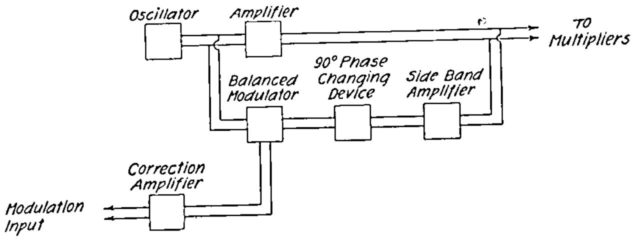


Fig. 1

degrees (or 270 degrees) with respect to the phase of the electromotive force applied to the grids of the balanced modulators. Hence it follows that the phase of the currents existing in the plate circuit of the amplifier of the output of the balanced modulator (at the peak of the modulation voltage) is either ninety degrees or 270 degrees apart from the phase of the current existing in the plate circuit of the amplifier of the

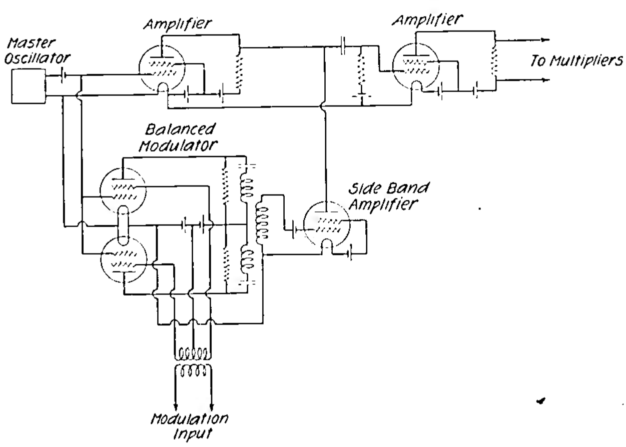


Fig. 2

unmodulated master oscillator current. Therefore the voltages which they develop across the common resistance load will be ninety degrees apart.

The resulting effect on the phase of the voltage developed across the resistance in the plate circuits of these two amplifiers when modulation is applied, compared to the phase of the voltage which would exist there in the absence of modulation will appear from Fig. 3. It will be observed from the vector diagrams that the phase of the voltage across

the common resistance load is alternately advanced and retarded by the combination of the modulated and unmodulated components and that the maximum phase shift is given by an angle whose tangent is the sum of the peak values of the two side frequencies divided by the peak value of the unmodulated component. By keeping this angle

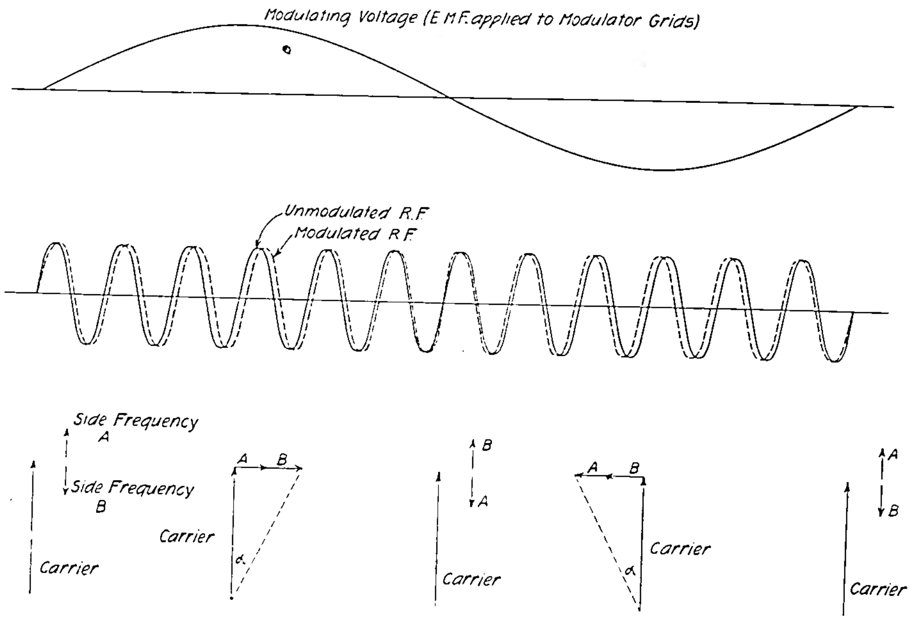


Fig. 3

sufficiently small (not greater than thirty degrees) it may be made substantially proportional to the amplitude of the two side frequencies and hence to the amplitude of the initial modulating current.[7] It will be observed that if the angle through which the phase is shifted be the same for all frequencies of modulation then the rate of increase or de-

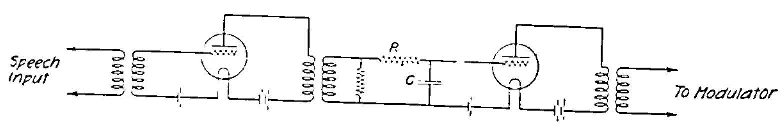


Fig. 4

crease of the angle will be proportional to the frequency of modulation and hence the deviation in frequency of the transmitted wave will be proportional to the frequency of the modulating current. In order to insure a frequency deviation which is independent of the modulation

[7] For the large angular displacements there will be an appreciable change in amplitude of the combined currents at double the frequency of the modulating current. This variation in amplitude is not of primary importance and is removed subsequently by a limiting process.

frequency it is necessary that, for a constant impressed modulating electromotive force, the angle through which the phase is shifted be made inversely proportional to the frequency of the modulating current. This is accomplished by making the amplification of the input amplifier inversely proportional to frequency by means of the correction network shown in Fig. 4. The network consists of a high resistance in series with a capacity whose impedence for the lowest frequency of modulation is relatively small with respect to the series resistance. The voltage developed across the capacity which excites the succeeding amplifier stage is therefore inversely proportional to frequency and hence it follows that the angle through which the current is advanced or retarded becomes directly proportional to the amplitude of the modulating current and inversely proportional to its frequency. The resulting phase shift must be multiplied a great many times before a frequency modulated current which can be usefully employed is produced. This will be clear from an examination of the requirements of a circuit over which it is desired to transmit a frequency range from thirty to 10,000 cycles. Since the lowest frequency is limited to a phase shift of thirty degrees it follows that for 10,000 cycles the phase shift will be but 0.09 degree. The minimum phase shift for 100 per cent modulation of the transmitted wave is roughly forty-five degrees. A frequency multiplication of 500 times is required, therefore, to produce a wave which is fully modulated[8] and capable of being effectively handled by the receiver in the presence of disturbing currents.

Under ordinary conditions this multiplication of frequency can be realized without loss of linearity by a series of doublers and triplers operated at saturation provided the correct linkage circuits between the tubes are employed. Where however the wide band frequency swing which will be described subsequently in this paper is employed unexpected difficulties arise. These also will be dealt with subsequently.

From the foregoing description it will be seen that this method of obtaining frequency modulation consists in producing initially phase modulation in which the phase shift is inversely proportional to the frequency of modulation and converting the phase modulated current into a frequency modulated one by successive multiplications of the phase shift. The frequency stability, of course, is the stability attainable by a crystal controlled oscillator and the symmetry of the deviation may be made substantially perfect by compensating such asymmetrical action in the system as may occur. With the method of phase

[8] One in which the side frequencies are sufficiently large with respect to the carrier to make it possible to produce at the receiver 100 per cent modulation in amplitude, without the use of expedients which affect unfavorably the signal-to-noise ratio.

shifting shown in Fig. 2 there is an asymmetry which is of importance when the frequency of modulation is high compared to the master oscillator frequency. It occurs in the plate transformer of the balanced modulator. The plate circuits of these tubes are substantially aperiodic and consequently the amplitudes of the upper and lower side frequencies are approximately equal and from this it follows that the electromotive forces induced in the secondary are directly proportional to the values of these frequencies. Where the master oscillator frequency is 50,000 cycles and a frequency of modulation of 10,000 cycles is applied, the upper side frequency may be fifty per cent greater than the lower. This inequality may be compensated by a resistance-capacity network introduced subsequent to the point at which the combination of carrier and side frequencies is effected but prior to any point at which loss of linearity of amplitude occurs. The level in the amplifiers ahead of the compensating network must be kept sufficiently low so that the operation of the system is linear. After the side frequencies are equalized amplitude linearity ceases to be of importance.

The performance of transmitters operating on this principle has been in complete accord with expectations. While the arrangements may seem complex and require a large amount of apparatus the complexity is merely that of design, not of operation. The complete arrangement, up to the last few multiplier stages may be carried out most effectively with receiving type tubes, these last multiplier stages consisting of power type pentodes for raising the level to that necessary to excite the usual power amplifiers.

The Receiving System

The most difficult operation in the receiving system is the translation of the changes in the frequency of the received signal into a current which is a reproduction of the original modulating current. This is particularly true in the case of the transmission of high fidelity broadcasting. It is, of course, essential that the translation be made linearly to prevent the generation of harmonics but it must also be accomplished in such a manner that the signaling current is not placed at a disadvantage with respect to the various types of disturbances to which radio reception is subject. In the particular type of translation developed for this purpose which employs the method of causing the changes in frequency to effect changes in amplitude which are then rectified by linear detectors, it is essential that for the maximum deviation of the transmitted frequency there shall be a substantial amplitude modulation of the received wave. At first sight it might appear that 100 per cent or complete modulation would be the ideal, but there are

objections to approaching this limit too closely. It will, however, be clear that where the translation is such that only a few per cent amplitude modulation results from the maximum deviation of the frequency of the transmitted wave the receiver is hopelessly handicapped with respect to amplitude disturbances. This is true because even when the level of the voltage applied to the conversion system is kept constant by a current limiting device or automatic volume control there still remains those intervals wherein the incoming disturbances arrive in the proper phase to neutralize the signaling current in the detector, effecting thereby substantially complete modulation of the rectified current or the intervals wherein the disturbing currents themselves effect greater amplitude changes than the signal itself by cross modulation of its frequency.

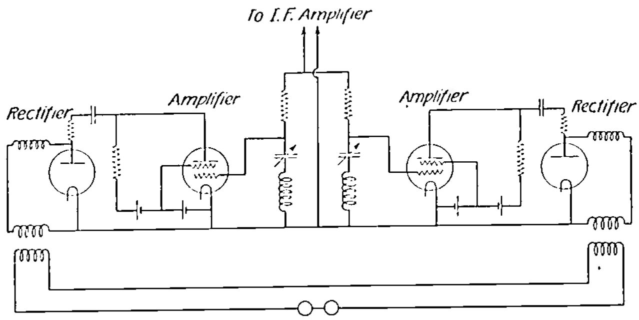


Fig. 5

An arrangement in which linear conversion can be effected without handicapping the system with respect to amplitude disturbances is illustrated diagrammatically in Fig. 5. Two branch circuits each containing resistance, capacity, and inductance in series as shown are connected to the intermediate-frequency amplifier of a superheterodyne at some suitable frequency. One capacity and inductance combination is made nonreactive for one extreme of the frequency band which the signal current traverses and the other capacity and inductance combination is made nonreactive for the other end of the band. The resistances are chosen sufficiently high to maintain the current constant over the frequency range of the band; in fact, sufficiently high to make each branch substantially aperiodic. The reactance characteristics taken across each capacity and inductance combination will be as illustrated in Fig. 6 by curves A and B. Since the resistances in series with the reactance combinations are sufficient to keep the current constant throughout the frequency band it follows that the voltages developed across each of the two combinations will be proportional to their reactances as is illustrated in curves A' and B'. The two voltages are

applied respectively to the two equal aperiodic amplifiers, each of which is connected to a linear rectifier. The rectifiers are in series with equal output transformers whose secondaries are so poled that changes in the rectifier currents resulting from a change in the frequency of the received signal produce additive electromotive forces in their secondaries. Since amplifiers and rectifiers are linear the output currents will follow the amplitude variations created by the action of the capacity-inductance combinations. While the variation in reactance is not linear with respect to the change of frequency, particularly where the width of the band is a substantial percentage of the frequency at which the operation takes place, as a practical matter, by the proper choice of values together with shunts of high resistance or reactance

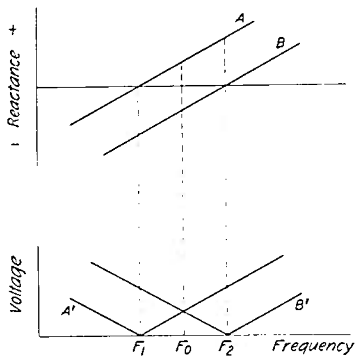


Fig. 6

these characteristics may be rendered sufficiently straight within the working range to meet the severest requirements of high fidelity broadcasting. The operation of the system is aperiodic and capable of effecting 100 per cent modulation if desired, this last depending on the separation of the two nonreactive points with respect to the frequency swing. Generally the setting of the nonreactive frequency points should be somewhat beyond the range through which the frequency is swung.

There is shown in Fig. 7 an alternative arrangement of deriving the signal from the changes in frequency of the received wave which has certain advantages of symmetry over the method just described. In this arrangement a single capacity-inductance combination with the nonreactive point in the center of the frequency band is used and the rectifiers are polarized by a current of constant amplitude derived from the received current. In this way, by properly phasing the polarizing current, which is in effect a synchronous heterodyne, differential rectifying action can be obtained. In Fig. 7 the amplified output of the receiver is applied across the single series circuit consisting of resistance R, capacity C, and inductance L. The reactance of C and L are equal

for the mid-frequency point of the band and the reactance curve is as illustrated in A of Fig. 8. At frequencies above the nonreactive

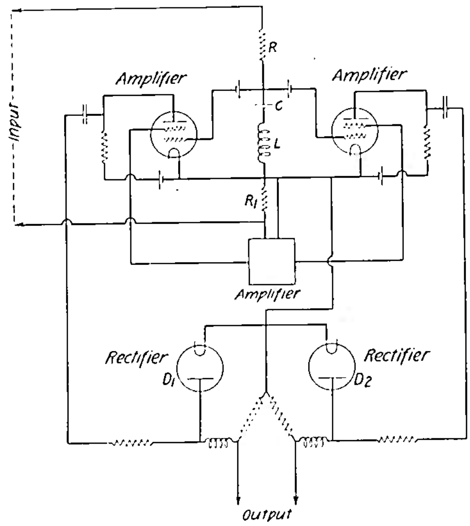


Fig. 7

point the combination acts as an inductance; at frequencies below the nonreactive point as a capacity and the phase of the voltage developed across the combination with respect to the current through it

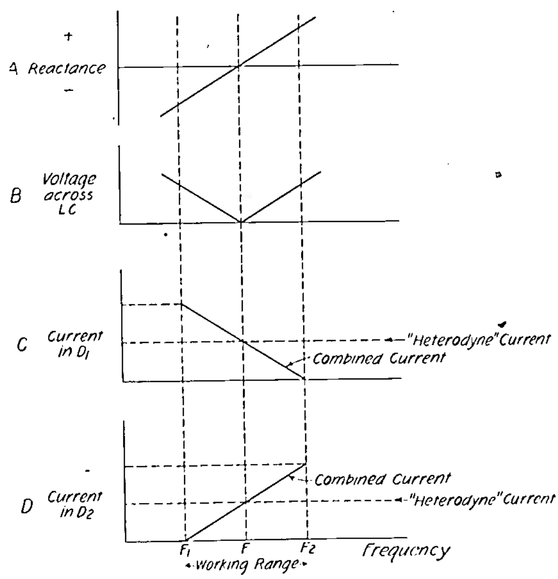


Fig. 8

differs, therefore, by 180 degrees above and below the nonreactive point. Since the current through the circuit is maintained constant over the working range by the resistance R and since the resistance of the

capacity C and inductance L may be made very low the electromotive force developed across C and L is of the form shown in curve B. This curve likewise represents the variation in voltage with variation in frequency which is applied to the grids of the amplifiers and eventually to the two rectifiers D_1 and D_2.

The heterodyning or polarizing voltage is obtained by taking the drop across the resistance R_1, amplifying it, changing its phase through ninety degrees and applying the amplified voltage to the screen grids of the amplifiers in opposite phase. The characteristic of this amplifying and phase changing system must be flat over the working range. Under these conditions the signaling and heterodyning voltages are exactly in phase in one rectifier and 180 degrees out of phase in the other, and hence for a variable signaling frequency the rectifying characteristics are as shown in curves C and D the detector outputs being cumulatively combined for frequency changes. Adjustment of the relative amplitudes of the signaling and polarizing voltages in the rectifier controls the degree of amplitude modulation produced from 100 per cent down to any desired value.

PART II

With the foregoing description of the instrumentalities for transmitting and receiving frequency modulated waves it is now in order to consider the main object of the paper; the method of reducing disturbances and the practical results obtained by its use.

Method of Reducing Disturbances

The basis of the method consists in introducing into the transmitted wave a characteristic which cannot be reproduced in disturbances of natural origin and utilizing a receiving means which is substantially not responsive to the currents resulting from the ordinary types of disturbances and fully responsive only to the type of wave which has the special characteristic.

The method to be described utilizes a new principle in radio signaling the application of which furnishes an interesting conflict with one which has been a guide in the art for many years; i.e., the belief that the narrower the band of transmission the better the signal-to-noise ratio. That principle is not of general application. In the present method an opposite rule applies.

It appears that the origin of the belief that the energy of the disturbance created in a receiving system by random interference depended on the band width goes back almost to the beginning of radio. In the days of spark telegraphy it was observed that "loose coupling" of the conventional transmitter and receiver circuits produced

a "sharper wave" and that interference from lightning discharges, the principle "static" of those days of insensitive and nonamplifying receivers was decreased. Further reduction in interference of this sort occurred when continuous-wave transmitters displaced the spark and when regeneration narrowed the band width of the receiving system. It was observed, however, that "excessive resonance" must not be employed either in telegraphic or more particularly in telephonic signaling or the keying and speech would become distorted. It was concluded in a qualitative way that there was a certain "selectivity" which gave the best results.

In 1925 the matter was placed on a quantitative basis by Carson[9] where in a mathematical treatment of the behavior of selective circuits when subjected to irregular and random interference (with particular reference to "static"), on the basis of certain assumptions, the proposition was established that "if the signaling system requires the transmission of the band of frequencies corresponding to the interval $\omega_2-\omega_1$ and if the selective circuit is efficiently designed to this end, then the mean square interference current is proportional to the frequency band width $(\omega_2-\omega_1)/2\pi$.

Hazeltine[10] pointed out that when a detector was added to such a system and a carrier of greater level than the interference currents was present, that for aural reception only those components of the interfering current lying within audible range of the carrier frequency were of importance and that Carson's theory should be supplemented by the use of a factor equal to the relative sensitivity of the ear at different frequencies.

With the discovery of shot effect and thermal agitation noises and the study of their effect on the limit of amplification quantitative relations akin to those enunciated by Carson with respect to static were found to exist.

Johnson,[11] reporting the discovery of the electromotive force due to thermal agitation and considering the problem of reducing the noise in amplifiers caused thereby, points out that for this type of disturbance the theory indicates, as in the Carson theory, that the frequency range of the system should be made no greater than is essential for the proper transmission of the applied input voltage, that where a voltage of constant frequency and amplitude is used one may go to extremes in

[9] J. R. Carson, "Selective circuits and static interference," *Bell Sys. Tech. Jour.*, vol. 4, p. 265, (1925).

[10] L. A. Hazeltine, Discussion on "The shielded neutrodyne receiver," Proc. I.R.E., vol. 14, pp. 408, 409; June, (1926).

[11] J. B. Johnson, "Thermal agitation of electricity in conductors, *Phys. Rev.*, vol. 32, no. 1, July, (1926).

making the system selective and thereby proportionately reducing the noise, but that when the applied voltage varies in frequency or amplitude the system must have a frequency range which takes care of these variations and the presence of a certain amount of noise must be accepted.

Ballantine[12] in a classical paper discussing the random interference created in radio receivers by shot and thermal effects obtained a complete expression for the noise output.[13]

Johnson and Llewellyn,[14] in a paper dealing generally with the limits to amplification, point out that in a properly designed amplifier the limit resides in thermal agitation in the input circuit to the amplifier, that the power of the disturbance in the output of the amplifier is proportional to its frequency range and that this, the only controllable factor in the noise equation, should be no greater than is needed for the transmission of the signal. A similar conclusion is reached in the case of a detector connected to the output of a radio-frequency amplifier and supplied with a signal carrier.

It is now of interest to consider what happens in a linear detector connected to the output of a wide band amplifier which amplifies uniformly the range from 300 to 500 kilocycles. Assume that the amplification be sufficiently great to raise the voltage due to thermal agitation and shot effect to a point sufficient to produce straight-line rectification and that no signal is being received. Under these conditions the frequencies from all parts of the spectrum between 300 and 500 kilocycles beat together to contribute in the output of the detector to the rough hissing tone with which the art is familiar. The spectrum of frequencies in the rectified output runs from some very low value which is due to adjacent components throughout the range beating with one another to the high value of 200 kilocycles caused by the interferences of the extremes of the band.

It is important to note that all parts of the 300- to 500-kilocycle spectrum contribute to the production in the detector output of those frequencies with which we are particularly interested—those lying within the audible range.

[12] Stuart Ballantine, "Fluctuation noise in radio receivers," Proc. I.R.E., vol. 18, pp. 1377–1387; August, (1930).

[13] Ballantine expressed his result as follows: "In a radio receiver employing a square-law detector and with a carrier voltage impressed upon the detector, the audio-frequency noise, as measured by an instrument indicating the average value of the square of the voltage (or current), is proportional to the area under the curve representing the square of the over-all transimpedance (or of the transmission) from the radio-frequency branch in which the disturbance originates to the measuring instrument as a function of frequency and proportional to the square of the carrier voltage."

[14] J. B. Johnson and F. B. Llewellyn, "Limits to amplification," *Trans. A.I.E.E.*, vol. 53, no. 11, November, (1934).

Assume now that an unmodulated signal carrier is received of, for example, 400 kilocycles and that its amplitude is greater than that of the disturbing currents. Under these circumstances an entirely new set of conditions arise. The presence of the 400-kilocycle current stops the rectification of the beats which occur between the various components of the spectrum within the 300- to 500-kilocycle band and forces all rectification to take place in conjunction with the 400-kilocycle carrier. Hence in the output of the rectifier there is produced a series of frequencies running from some low value up to 100 kilocycles. The lowest frequency is produced by those components of the spectrum which lie adjacent to the 400-kilocycle current, the highest by those frequencies[15,16] which lie at the extremity of the band; i.e., 300 and 500 kilocycles, respectively.

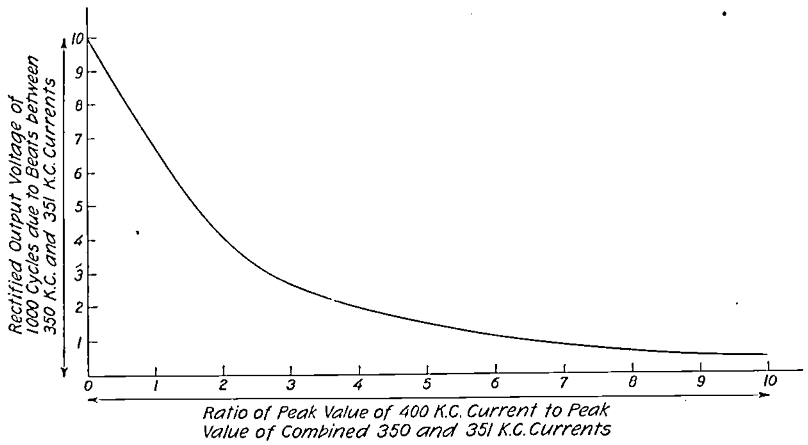


Fig. 9

The characteristics of the rectifiers and the magnitude of some of the effects involved in the above-described action may be visualized by reference to the succeeding figures. The actual demodulation of the beats occurring between adjacent frequency components by the presence of the 400-kilocycle current is shown by the characteristic of Fig. 9, which illustrates what happens to the output voltage of a rectifier produced by beating together two equal currents of 350 and 351 kilocycles, respectively, when a 400-kilocycle current is introduced in the same rectifier and its amplitude progressively increased with respect

[15] It has been pointed out by Ballantine[16] that it is improper to speak of the amplitude of a single component of definite frequency and that the proper unit is the noise per frequency interval. This is, of course, correct, but to facilitate the physical conception of what occurs in this system the liberty is taken of referring to the noise components as though they were of continuous sine wave form. The behavior of the system may be checked by actually introducing from a local generator such components.

[16] "Fluctuation noise in radio receivers," Proc. I.R.E., vol. 18, pp. 1377–1387; August, (1930).

to the amplitude of these two currents. The characteristic was obtained with the arrangement shown in Fig. 10, in which two oscillators of 350 and 351 kilocycles produced currents of equal strength in a linear rectifier, this rectifier consisting of a diode in series with 10,000 ohms resistance. The output of the rectifier is put through a low-pass filter, a voltage divider, and an amplifier. The 400-kilocycle current is intro-

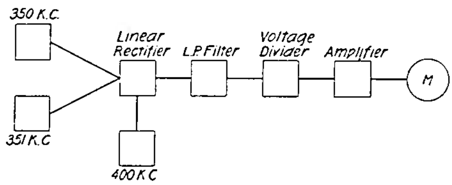


Fig. 10

duced into the rectifier without disturbing the voltage relations of the other two oscillators and the effect on the rectified output voltage observed as the 400-kilocycle current is increased. The purpose of the low-pass filter is to prevent the indicating instrument from responding to the 49- or 50-kilocycle currents produced by the interaction of the 350- and 351-kilocycle currents with the current of 400 kilocycles. The

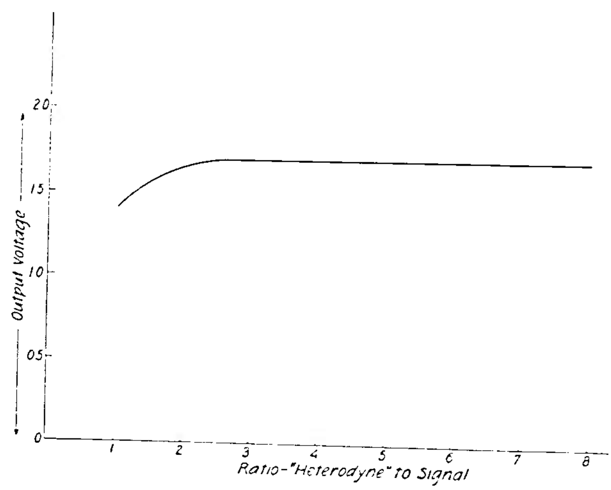


Fig. 11

linearity characteristic of the rectifier is shown in Fig. 11 where the voltage produced by the beats between a current of constant amplitude and one whose amplitude is raised from equality with, to many times the value of, the first current is plotted against the ratio of the two. The linearity of the rectifier is such that after the ratio of the current becomes two to one no further increase in rectifier output voltage results. In fact with the levels used in these measurements when the

two currents are equal there is an efficiency of rectification of only about twenty per cent less than the maximum obtained.

It is important to note here that the only frequencies in the spectrum which contribute to the production of currents of audible frequency in the detector output circuit are those lying within audible range of the signal carrier. We may assume this range as roughly from 390 to 410 kilocycles. The frequencies lying beyond these limits beat against the 400-kilocycle carrier and of course are rectified by the detector but the rectified currents which are produced are of frequencies which lie beyond the audible range and produce therefore no effect which is apparent to the ear. It follows that if the signal carrier is somewhat greater in amplitude than the disturbing currents the signal-to-noise ratio for a receiver whose band of admittance covers twice the audible range will be the same as for one whose band width is many times that value. (There are, of course, certain second order effects, but they are of such minor importance that the ear cannot detect them.) The amplitude of the disturbances in the detector output, will vary in accordance as the components of the disturbing currents come into or out of phase with the signal carrier, the rectified or detector output current increasing above and decreasing below the level of the rectified carrier current by an amount proportional to the amplitude of the components of the 300–500-kilocycle band. The reasons for the independence of the signal-to-noise ratio of the band width under the circumstances which have been described should now be apparent. In any event, it can be readily demonstrated experimentally.

It is now in order to consider what happens when a current limiting device is introduced between the output of the amplifier and the detector input. (Assume signal level still above peak noise level.) Two effects will occur. One of the effects will be to suppress in the output circuit of the limiter all components of the disturbing currents which are in phase with, or opposite in phase to, the 400-kilocycle carrier. The other effect will be to permit the passage of all components of the disturbing currents which are in quadrature with the 400-kilocycle current.

Both the above effects are brought about by a curious process which takes place in the limiter. Each component within the band creates an image lying on the opposite side of the 400-kilocycle point whose frequency difference from the 400-kilocycle current is equal to the frequency difference between that current and the original component. The relative phase of the original current in question, the 400-kilocycle current and the image current is that of phase modulation—that is, at the instant when the original component and its

image are in phase with each other, the 400-kilocycle current will be in quadrature with them both and at the instant that the 400-kilocycle current is in phase with one of these two frequencies, it will be out of phase with the other.

The relation (obtained experimentally) between the amplitudes of the original current and the image is illustrated by the curve of Fig. 12,

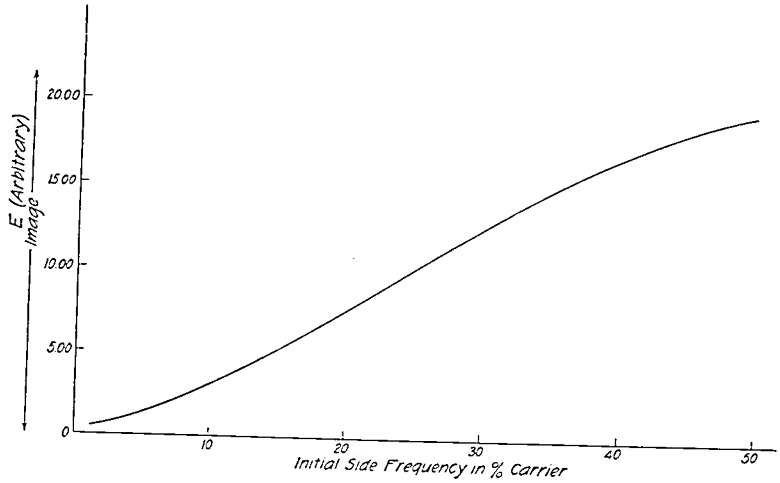


Fig. 12

which shows the relation between the amplitude of a 390-kilocycle current introduced into a limiter along with the 400-kilocycle current and the resulting 410-kilocycle image in terms of percentage amplitude of the 400-kilocycle current. It will be obvious from the curve that in the region which is of interest—that is, where the side frequencies are smaller than the mid-frequency—that the effect is substantially linear.

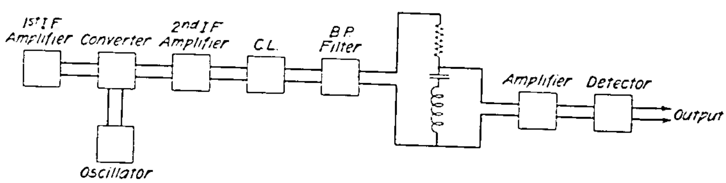


Fig. 13

With the above understanding of what takes place in the current limiter it is now in order to consider what happens when a selective system as illustrated in Fig. 13 is interposed between the limiter and the detector. (The band-pass filter is for the purpose of removing limiter harmonics.) A rough picture of what occurs may be had by considering a single component of the interference spectrum. Suppose

this component to be at 390 kilocycles and that by the action already explained it has created its image at 410 kilocycles. These two frequencies are equal in amplitude and so phased with respect to each other and with respect to the 400-kilocycle carrier that no amplitude change results.

Assume now that the selective system has the characteristic *MN* which as shown in Fig. 14 is designed to give complete modulation for a ten-kilocycle deviation of frequency. Since at 390 kilocycles the reactance across the capacity-inductance combination is zero and at 410 kilocycles double what it is at 400 kilocycles it follows that the 390-kilocycle component becomes equal to zero but the ratio of the 410-kilocycle component to the 400-kilocycle carrier is doubled; that

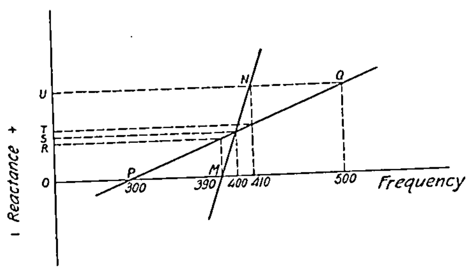


Fig. 14

is, it is twice as great as is the ratio in the circuits preceding the selective system. The change in amplitude, therefore, becomes proportional to *OU*. Therefore in combination with the 400-kilocycle carrier a variation in amplitude is produced which is substantially identical with that which would be obtained were the current limiter removed and the selective system replaced by an aperiodic coupling of such value that the same detector level were preserved.

Now consider what occurs when a selective system having the characteristic such as *PQ* and requiring a deviation of 100 kilocycles to produce full modulation is employed instead of one such as *MN*, where a ten-kilocycle deviation only is required. Assume the same conditions of interference as before. The 400-kilocycle voltage applied to the rectifier will be the same as before, but the *relative amplitudes of the 390- and 410-kilocycle voltages will only be slightly changed.* The 410-kilocycle voltage will be increased from a value which is proportional to *OS* to one which is proportional to *OT* and the 390-kilocycle voltage will be reduced from a value proportional to *OS* to one proportional to *OR*. The difference in value of the two frequencies will be proportional to the difference between *OS* and *OT* or *RT*, and the change in amplitude produced by their interaction with the 400-

kilocycle current will be likewise proportional to RT. The reduction in the amplitude of the disturbance as measured in the detector output by the use of a 200-kilocycle wide selective system as compared to the use of one only twenty kilocycles wide is therefore the ratio RT/OU. In this case it is ten per cent. The power ratio is the square of this or one per cent.

The above reasoning holds equally well if a balanced rectifying system is used where the characteristics of the selective system are as shown in Fig. 15. The output of the system insofar as voltages resulting from changes in frequency are concerned is the sum of outputs of the two sides of the balance.

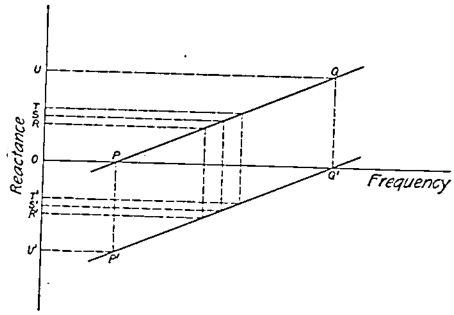


Fig. 15

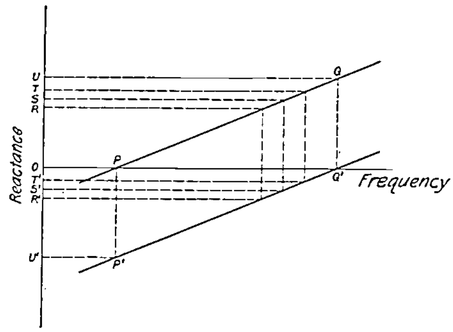


Fig. 16

It is of course clear that disturbing currents lying farther from the 400-kilocycle point than the ten-kilocycle limit will, by interaction with the 400-kilocycle current, produce larger values of rectified current than those lying within that band. *But the rectified currents produced in the detector output by those components of frequency which lie at a greater than audible frequency distance from the 400-kilocycle current will be beyond the audible range and hence will produce no disturbance which is audible.* (It is generally advisable to eliminate them from the audio amplifier by a low-pass filter to prevent some incidental rectification in the amplifier making their variations in amplitude audible.)

It remains only to consider what happens when the frequency of the 400-kilocycle current is varied in accordance with modulation at the transmitter. It is clear from Fig. 14 that when the selective system has the characteristic MN that a deviation of 10,000 cycles will produce complete modulation of the signal or a change in amplitude proportional to OU. Similarly, when the characteristic is according to the curve PQ it is clear that a 100,000-cycle deviation is required to produce complete modulation, which is likewise proportional to the same value OU. As the signal current is swung back and forth over the range of frequencies between 300 and 500 kilocycles the band of fre-

quencies from which the audible interference is derived continually changes, the band progressively lying about ten kilocycles above and ten kilocycles below what we may call the instantaneous value of the frequency of the signal. The effect is illustrated by Fig. 16 and from this it will be seen that the amplitude of the disturbances in the output circuit of the rectifiers, which is proportional to the sum of RT and $R'T'$ will be constant. This will be true where the ratio of the amplitude of the signal to the disturbing currents is sufficiently large—where this condition does not exist then there are certain other effects which modify the results, but these effects will only be of importance at the limits of the practical working range.

Comparison of Noise Ratios of Amplitude and Frequency Modulation Systems

From the foregoing description it will be clear that as between two frequency modulation systems of different band widths the signal-to-noise power ratio in the rectified output will vary directly as the square of the band width (provided the noise voltage at the current limiter is less than the signaling voltage). Thus doubling the band width produces an improvement of 4 to 1 and increasing it tenfold an improvement of 100 to 1.

The comparison of relative noise ratios of amplitude and frequency modulation systems cannot be made on so simple a basis as there are a number of new factors which enter, particularly when the comparison is viewed from the very practical aspect of how much greater power must be used with an amplitude modulated transmitter than with a frequency modulated one. If the academic comparison be made between a frequency modulated system having a deviation of ten kilocycles and an amplitude modulated one of similar band width and the *same carrier* level (also same fidelity), it will be found that the signal-to-noise voltage ratio as measured by a root-mean-square meter will favor the frequency modulation system by about 1.7 to 1, and that the corresponding power ratio will be about 3 to 1. This improvement is due to the fact that in the frequency modulation receiver it is only those noise components which lie at the extremes of the band; viz., ten kilocycles away from the carrier which, by interaction with the carrier (when unmodulated) can produce the same amplitude of rectified current as will be produced by the corresponding noise component in the amplitude modulated receiver.

Those components which lie closer to the carrier than ten kilocycles will produce a smaller rectified voltage, the value of this depending on their relative distance from the carrier. Hence the distribution of en-

ergy in the rectified current will not be uniform with respect to frequency but will increase from zero at zero frequency up to a maximum at the limit of the width of the receiver, which is ten kilocycles in the present case. The root-mean-square value of the voltage under such a distribution is approximately 0.6 of the value produced with the uniform distribution of the amplitude receiver.

Similarly in comparing an amplitude modulation system arranged to receive ten-kilocycle modulations and having, of course, a band width of twenty kilocycles, with a 100-kilocycle deviation frequency

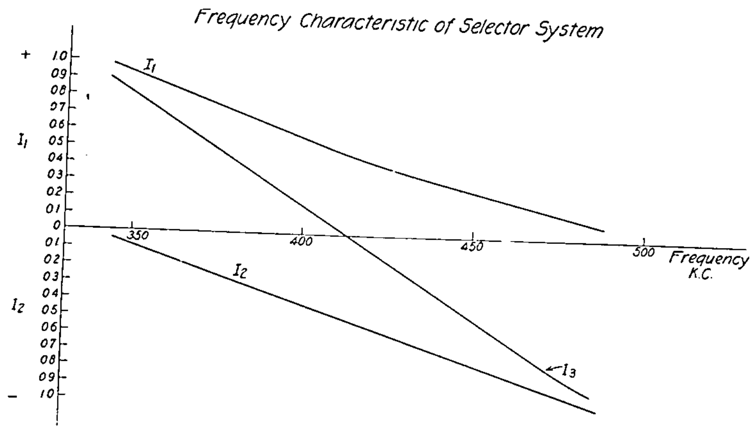


Fig. 17

modulation system (same carrier level and same fidelity) there will be an improvement in noise voltage ratio of

$$1.7 \times \frac{\text{deviation}}{\text{audio-frequency range}} \quad \text{or} \quad 1.7 \times \frac{100}{10} = 17.$$

The above comparisons have been made on the basis of equal carrier. The practical basis of comparison between the two is that of half carrier for the amplitude modulation and full carrier for the frequency modulation system. This results in about the equivalent amount of power being drawn from the mains by the two systems. On this basis the voltage improvement becomes thirty-four and the signal-to-noise power ratio 1156. Where the signal level is sufficiently large with respect to the noise it has been found possible to realize improvements of this order.

The relative output signal-to-noise ratios of an amplitude modulation system fifteen kilocycles wide (7.5-kilocycle modulation frequency) and a frequency modulation system 150 kilocycles wide (75-kilocycle deviation) operating on forty-one megacycles have been compared on the basis of equal fidelity and half carrier for amplitude modulation,

The characteristic of the selective system for converting frequency changes to amplitude changes, which was used, is shown in Fig. 17. The variation of the output signal-to-noise ratio with respect to the corresponding radio-frequency voltage ratio is illustrated in Fig. 18. The curves show that where the radio-frequency peak voltage of the noise measured at the current limiter is less than ten per cent of the

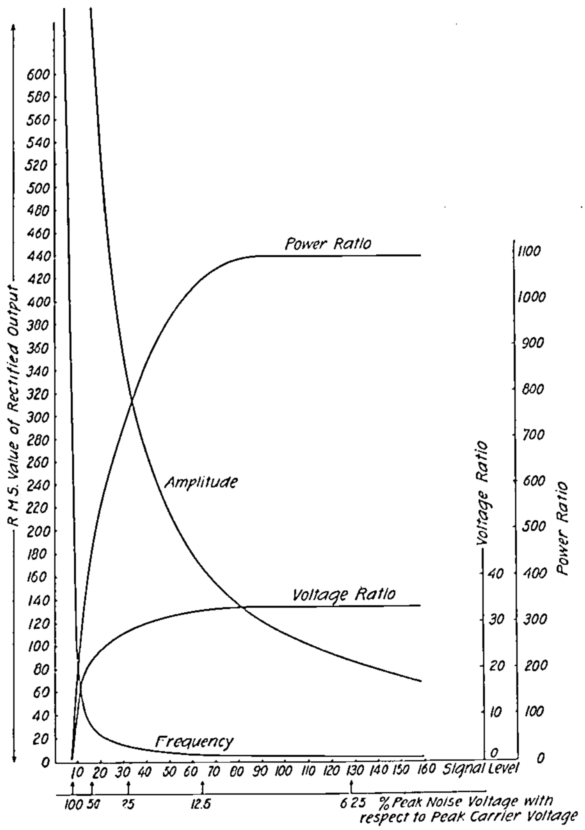


Fig. 18

signal peak voltage then the energy of the disturbance in the rectified output will be reduced by a factor which is approximately 1100 to 1. When the peak radio-frequency noise voltage is twenty-five per cent of the signal peak voltage then the energy of the disturbance in the rectified output has been reduced to about 700 to 1, and when it is fifty per cent the reduction of the disturbance drops below 500 to 1. Finally when the noise and signal peak voltages become substantially equal the improvement drops to some very low value. While it is unfortunate, of course, that the nature of the effect is such that the amount of noise reduction becomes less as the noise level rises with respect to the signal, nevertheless this failing is not nearly so important

as it would appear. In the field of high fidelity broadcasting a signal-to-noise voltage ratio of at least 100 to 1 is required for satisfactory reception. It is just within those ranges of noise ratios which can be reduced to this low level that the system is most effective.

The arrangements employed in obtaining these characteristics and the precautions which must be observed may perhaps be of interest. As it was obviously impracticable to vary the power of a transmitter over the ranges required or to eliminate the fading factor except over short periods of time an expedient was adopted. This expedient consisted in tuning the receiver to the carrier of a distant station, determining levels and then substituting for the distant station a local signal generator, the distant station remaining shut down except as it was

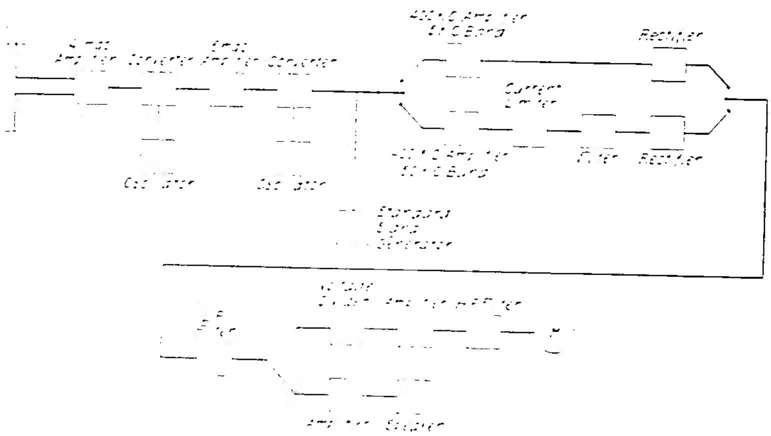


Fig. 19

called upon to check specific points on the curve. Observations were taken only when the noise was due solely to thermal agitation and shot effect.

Fig. 19 shows the arrangement of apparatus. The receiver was a two-intermediate-frequency superheterodyne with provision for using either a narrow band second intermediate amplifier with the amplitude modulation system or a wide band amplifier with the frequency modulation system. The band width of the amplitude modulation system was fifteen kilocycles or twice the modulation frequency range. The band width of the frequency modulation receiver was 150 kilocycles or twice the frequency deviation. Provision was made for shifting from one intermediate amplifier to the other without disturbing the remainder of the system. The forty-one-megacycle circuits and the first intermediate amplifier circuits were wide enough to pass the frequency swing of 150 kilocycles. Identical detection systems were used, the frequency modulation detector being preceded by a selective system for

translating changes in frequency into changes in amplitude. The output circuits of the detectors were arranged to be connected alternately to a 7500-cycle low-pass filter with a voltage divider across its output. An amplifier with a flat characteristic over the audible range and a root-mean-square meter connected through a high-pass, 500-cycle filter provided the visual indication.

The standard signal was introduced into the input of the two branches of the second intermediate-frequency stage at 400 kilocycles. As long as the receiver is linear between the antenna and the point at which the standard signal is introduced it is immaterial whether the signal be of forty-one megacycles, six megacycles, or 400 kilocycles. This has been checked experimentally but 400 kilocycles was chosen on account of the greater accuracy of the signal generator on low frequencies.

The relative noise levels to be compared varied over such ranges that lack of linearity had to be guarded against and readings were made by bringing the output meter to the same point on the scale each time by adjustment of the voltage divider, and obtaining the relative voltages directly from the divider.

Two other precautions are essential. The absolute value of the noise voltage on the frequency modulation system becomes very low for high signal levels. If the voltages due to thermal agitation and shot effect are to be measured rather than those due to the power supply system the output meter must be protected by a high-pass filter of high attentuation for the frequencies produced by the power system. The cutoff point should be kept as low as possible since because of the difference in the distribution of energy in the rectified outputs of frequency and amplitude modulation receivers already referred to there is a certain error introduced by this filter which is small if the band width excluded by the filter is small but which can become appreciable if too much of the low-frequency part of the modulation frequency range be suppressed.

A second precaution is the use of a low-pass filter to cut off frequencies above the modulation range. Because of the wide band passed by the amplifiers of the frequency modulation part of the system there exists in the detector output rectified currents of frequencies up to seventy-five kilocycles. The amplitude of these higher frequencies is much greater than those lying within the audible range. The average detector output transformer will readily pass a substantial part of these superaudible frequencies which then register their effect upon the output meter although they in no way contribute to the audible disturbance.

The procedure which was followed in making the measurements we are considering consisted in tuning the receiver to the distant transmitter and adjusting the two detector levels to the same value for the respective carrier levels to be employed. This was done by cutting the carrier in half at the transmitter when the amplitude modulation detector level was being set and using full carrier for the adjustment of the frequency modulation detector. Each system was then modulated seventy-five per cent and output voltages checked against each other. If they were equal the modulation was removed and the relative noise voltages measured for the respective carrier levels. This gave the first point on the curve. The transmitter was then shut down and a local carrier introduced which gave the same level in the 400-kilocycle intermediate amplifier circuits as the half carrier distant signal. This level was directly ascertainable from the rectified detector current in the amplitude modulation system. From this point on the procedure was entirely within the control of the receiving station. The noise ratios could be compared at any signal level by adjusting the voltage introduced by the signal generator to any fraction of that of the distant signal, bringing the level in the amplitude modulation detector up to the same original value by adjustment of the amplification of the second intermediate amplifier (the frequency modulation detector stays at its point of reference because of the current limiter) and comparing the two output voltages. The level of the detector in the amplitude modulation receiver was of course set with the half carrier value of the signal generator and the output voltage measured at that level. The output voltage of the frequency modulation system was measured when twice that voltage was applied.

It is important to keep in mind just what quantities have been measured and what the curves show. The results are a comparison between the relative noise levels in the two systems (root-mean-square values) *when they are unmodulated*. In both an amplitude and in a frequency modulation receiver the noise during modulation may be greater than that obtained without modulation. In the frequency modulation receiver two principal sources may contribute to this increase, one of which is of importance only where the band for which the receiver is designed is narrow, the other of which is common to all band widths. If the total band width of the receiver is twenty kilocycles and if the deviation is, for example, ten kilocycles, then as the carrier frequency swings off to one side of the band, it approaches close to the limit of the filtering system of the receiver. Since the sides of the filter are normally much steeper than the selective system employed to convert the changes in frequency into amplitude variations and since the fre-

quency of the signaling current will have approached to within the range of good audibility of the side of the filter a considerable increase in both audibility and amplitude of the disturbance may occur, caused by the sides of the filter acting as the translating device. This effect is obviously not of importance where a wider frequency swing is employed.

The other source of noise which may occur when the signal frequency swings over the full range is found in systems of all band widths. It was first observed on an unmodulated signal when it was noted that swinging the intermediate frequency from the mid-point to one side or the other by adjustment of the frequency of the first heterodyne produced an increase in the amplitude and a change in the character of the noise. The effect was noted on a balanced detector system and at first it was attributed to the destruction of the amplitude balance as one detector current became greater than the other. Subsequently when it was noted that the increase in the noise was produced by the detector with the smaller current and that the effect was most pronounced when the signal level was relatively low, the explanation became apparent. As long as the signal frequency was set at the mid-point of the band its level in the detector was sufficiently large to prevent the production of audible beats between the noise components lying respectively at the two ends of the band where the reactance of the selective systems is a maximum.

When however the signal frequency moves over to one side of the band the amplitude of the voltage applied to one of the detectors progressively decreases, approaching zero as the frequency coincides with the zero reactance point of the selective system. The demodulating effect of the signaling current therefore disappears and the noise components throughout the band, particularly those at the other side of it, are therefore free to beat with each other. The noise produced is the characteristic one obtained when the high-frequency currents caused by thermal agitation and shot effect are rectified in a detector without presence of a carrier. The effect is not of any great importance on the ordinary working levels for simplex operation, although it may become so in multiplex operation. It indicates, however, that where the signal-to-noise level is low, complete modulation of the received signal by the conversion system is not desirable and that an adjustment of the degree of modulation for various relative noise levels is advantageous.

In the course of a long series of comparisons between the two systems a physiological effect of considerable importance was noted. It was observed that while a root-mean-square meter might show the same reading for two sources of noise, one derived from an amplitude

modulation, and the other from a frequency modulation receiver (both of the same fidelity) that the disturbance perceived by the ear was more annoying on the amplitude modulation system. The reason for this is the difference in the distribution of the noise voltage with respect to frequency in the rectified output currents of the two systems, the distribution being substantially uniform in the amplitude system but proportional to frequency in the frequency modulation system. Hence in the latter there is a marked absence of those frequencies which lie in the range to which the ear is the most sensitive. With most observers this difference results in their appraising a disturbance produced in the speaker by an amplitude modulation system as the equivalent of one produced therein by a frequency modulation system of about 1.5 times the root-mean-square voltage although of course the factor varies considerably with the frequency range under consideration and the characteristic of the individual's aural system.

On account of this difference in distribution of energy the correct method of procedure in making the comparison is that given in the article by Ballantine,[16] but lack of facilities for such determinations made necessary the use of a root-mean-square meter for the simultaneous measurement of the entire noise frequency range. The increase in noise voltage per frequency interval with the frequency may be readily demonstrated by means of the ordinary harmonic analyzer of the type now so generally used for the measurement of distortion. Because of the extremely narrow frequency interval of these instruments it is not possible to obtain sufficient integration to produce stable meter readings and apparatus having a wider frequency interval than the crystal filter type of analyzer must be used. The observation of the action of one of these analyzers will furnish convincing proof that peak voltmeter methods must not be used in comparing the rectified output currents in frequency and amplitude modulation receivers.

All the measurements which have been heretofore discussed were taken under conditions in which the disturbing currents had their origin in either thermal agitation or shot effect, as the irregularity of atmospheric disturbances or those due to automobile ignition systems were too irregular to permit reproducible results. The curves apply generally to other types of disturbances provided the disturbing voltage is not greater than that of the signal. When that occurs a different situation exists and will be considered in detail later.

There are numerous second order effects produced, but as they are of no great importance consideration of them will not be undertaken in the present paper.

The New York-Westhampton and Haddonfield Tests

The years of research required before field tests could even be considered were carried out in the Marcellus Hartley Research Laboratory at Columbia University. Of necessity both ends of the circuit had to be under observation simultaneously and a locally generated signal was used. The source of signal ultimately employed consisted of a standard signal generator based upon the principle of modulation already described and capable of giving 150,000 cycles swing on forty-four megacycles. The generator was also arranged to give amplitude modulated signals. Suitable switching arrangements for changing rapidly from frequency to amplitude modulation at either full or half carrier were set up and a characteristic similar to that of Fig. 18 ultimately obtained.

A complete receiving system was constructed and during the Winter of 1933–1934 a series of demonstrations were made to the executives and engineers of the Radio Corporation of America. That wholly justifiable suspicion with which all laboratory demonstrations of "static eliminators" should be properly regarded was relieved when C. W. Horn of the National Broadcasting Company placed at the writer's disposal a transmitter in that company's experimental station located on top of the Empire State Building in New York City. The transmitter used for the sight channel of the television system delivered about two kilowatts of power at forty-four megacycles to the antenna and it was the one selected for use. This offer of Mr. Horn's greatly facilitated the practical application of the system as it eliminated the necessity of transmitter construction in a difficult field and furnished the highly skilled assistance of R. E. Shelby and T. J. Buzalski, the active staff of the station at that time. Numerous difficulties, real and imaginary, required much careful measurement to ascertain their presence or absence and the relative importance of those actually existing. The most troublesome was due to the position of the transmitter, which is located on the eighty-fifth floor of the building and is connected by a concentric transmission line approximately 275 feet long with a vertical dipole antenna about 1250 feet above ground. Investigation of the characteristics of this link between transmitter and antenna showed it to be so poorly matched to the antenna that the resulting standing waves attained very large amplitude. The problem of termination afforded peculiar difficulties because of the severe structural requirements of the antenna above the roof and of the transmission line below it. It was however completely solved by P. S. Carter of the R.C.A. Communications Company in a very

beautiful manner, the standing waves being practically eliminated and the antenna broadened beyond all requirements of the modulating system contemplated. With the transmitter circuits no difficulty was encountered at this time. The frequency of the system was ordinarily controlled by a master oscillator operating at 1733 kilocycles which was multiplied by a series of doublers and a tripler to forty-four megacycles. The multiplier and amplifier circuits were found to be sufficiently broad for the purposes of the initial tests.

The crystal control oscillator was replaced by the output of the modulation system shown in Fig. 20 in which an initial frequency of 57.33 kilocycles was multiplied by a series of doublers up to the input frequency of the transmitter of 1733 kilocycles. It was found possible to operate this apparatus as it is shown installed in the shielded room

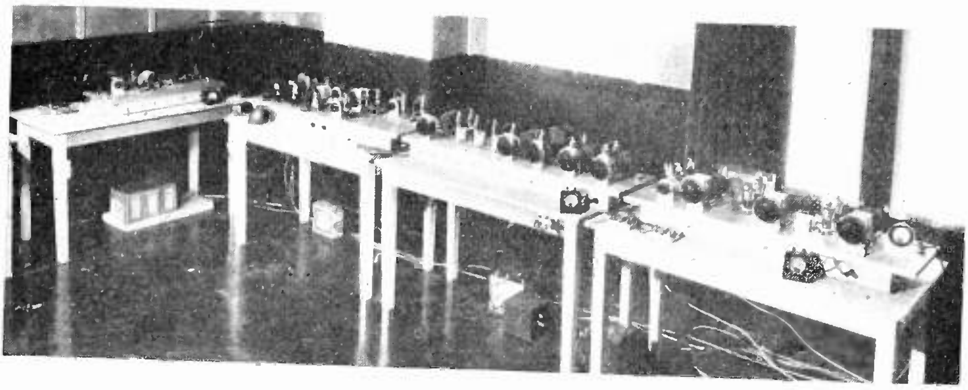


Fig. 20

of the television studio at the Empire State station as the shielding furnished ample protection against the effects of the high power stages of the transmitter located some seventy-five feet away.

The receiving site selected was at the home of George E. Burghard at Westhampton Beach, Long Island, one of the original pioneers of amateur radio, where a modern amateur station with all facilities, including those for rigging directive antennas, were at hand. Westhampton is about sixty-five miles from New York and 800 or 900 feet below line of sight.

The installation is illustrated in Figs. 21 and 22 which show both frequency and amplitude modulation receivers and some of the measuring equipment for comparing them. The frequency modulation receiver consisted of three stages of radio-frequency amplification (at forty-one megacycles) giving a gain in voltage of about 100. This frequency was heterodyned down to six megacycles where an amplification of about 2000 was available and this frequency was in turn hetero-

dyned down to 400 kilocycles where an amplification of about 1000 could be realized. Two current limiting systems in cascade each with a separate amplifier were used. At the time the photograph was taken the first two radio-frequency stages had been discarded.

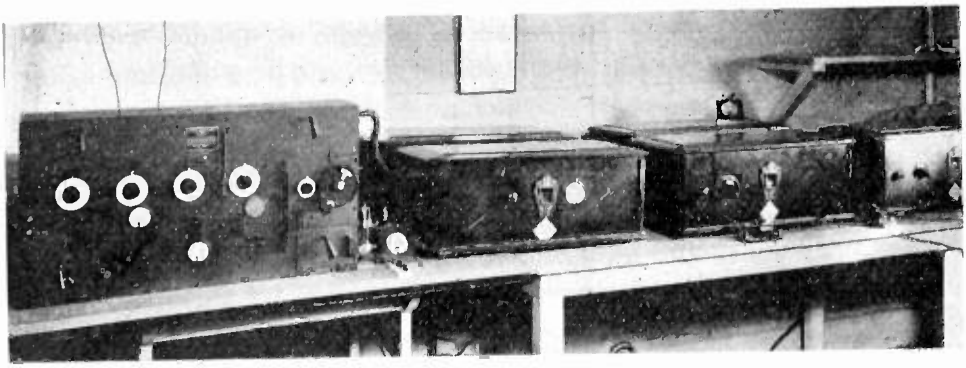


Fig. 21

The initial tests in the early part of June surpassed all expectations. Reception was perfect on any of the antennas employed, a ten-foot wire furnishing sufficient pickup to eliminate all background noises. Suc-

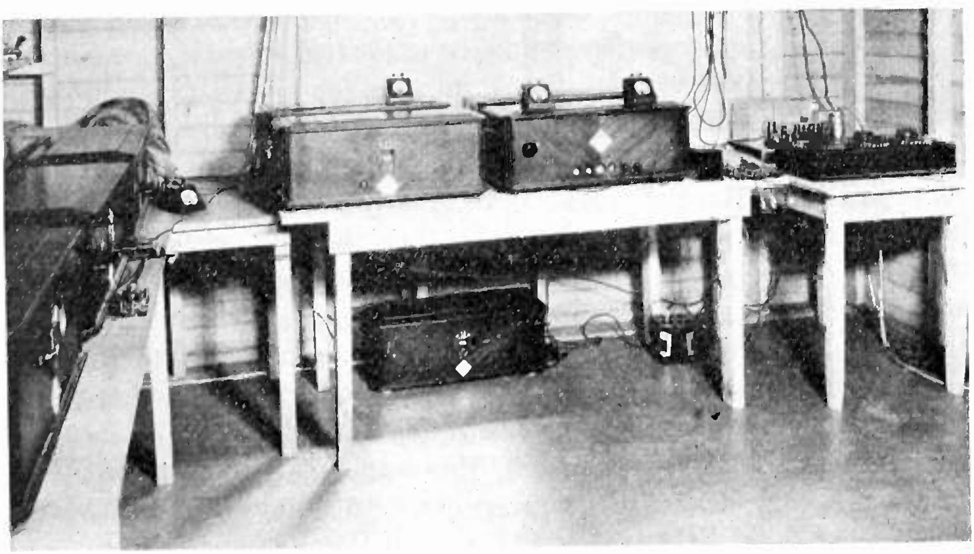


Fig. 22

cessive reductions of power at the transmitter culminated at a level subsequently determined as approximately twenty watts. This gave a signal comparable to that received from the regular New York broadcast stations (except WEAF, a fifty-kilowatt station approximately forty miles away).

The margin of superiority of the frequency modulation system over amplitude modulation at forty-one megacycles was so great that it was at once obvious that comparisons of the two were principally of academic interest.

The real question of great engineering and economic importance was the comparison of the ultra-short-wave frequency modulation system with the existing broadcast service and the determination of the question of whether the service area of the existing stations could not be more effectively covered than at present. The remainder of the month was devoted to such a comparison. With the Empire State transmitter operating with approximately two kilowatts in the antenna, at all times and under all conditions the service was superior to that provided by the existing fifty-kilowatt stations, this including station WEAF. During thunderstorms, unless lightning was striking within a few miles of Westhampton, no disturbance at all would appear on the system, while all programs on the regular broadcast system would be in a hopeless condition. Background noise due to thermal agitation and tube hiss were likewise much less than on the regular broadcast system.

The work at Westhampton demonstrated that in comparing this method of transmission with existing methods two classes of services and two bases of comparisons must be used. It was found that the only type of disturbance of the slightest importance was that caused by the ignition systems of automobiles, where the peak voltage developed by the interference was greater than the carrier level. In point-to-point communication this difficulty can be readily guarded against by proper location of the receiving system, and then thermal agitation and shot effect are the principal sources of disturbance; lightning, unless in the immediate vicinity, rarely producing voltages in excess of the carrier level which would normally be employed to suppress the thermal and shot effects. Under these conditions the full effect of noise suppression is realized and comparisons can be made with precision by means of the method already described in this paper. An illustration of the practical accomplishment of this occurred at Arney's Mount, the television relay point between New York and Camden of the Radio Corporation of America. This station is located about sixty miles from the Empire State Building and the top of the tower is only a few feet below line of sight. It is in an isolated spot and the noise level is almost entirely that due to the thermal and shot effects. It was noted by C. M. Burrill of the RCA Manufacturing Company who made the observations at Arney's Mount that with fifty watts in the antenna frequency modulated (produced by a pair of UX 852 tubes), a signal-

to-noise ratio of the same value as the two-kilowatt amplitude modulation transmitter (eight-kilowatt peaks) was obtained.

The power amplifier and the intermediate power amplifier of the frequency modulation transmitter is shown in Fig. 23. The signal with fifty watts output would undoubtedly have had a better noise ratio than the two-kilowatt amplitude modulation system had full deviation of seventy-five kilocycles been employed, but on the occasion it was not possible to use a deviation of greater than twenty-five kilocycles. It was also observed at the same time that when the plate voltage on the power amplifier was raised to give a power of the order of 200 watts in the antenna a better signal-to-noise ratio was obtained than

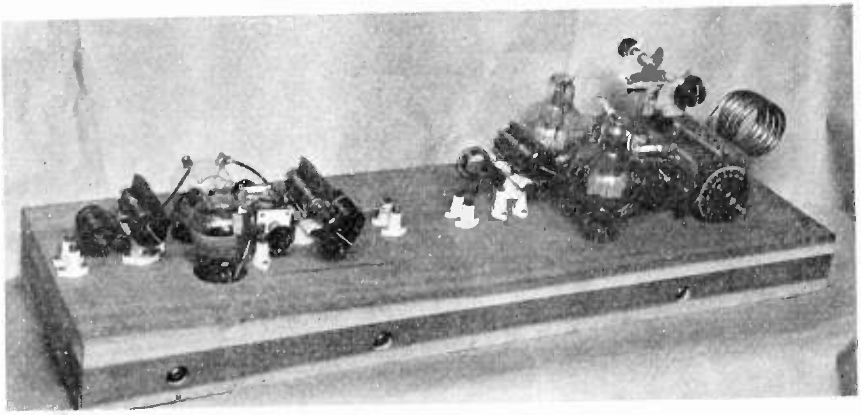


Fig. 23

that which could be produced by the two-kilowatt amplitude modulation. A casual comparison of the power amplifier stages of the frequency modulation transmitter shown in Fig. 23 with the water-cooled power amplifier and modulation stages of the Empire State transmitter is more eloquent than any curves which may be shown herein.

In the broadcast service no such choice of location is possible and a widely variable set of conditions must be met. Depending on the power at the transmitter, the elevation of the antenna, the contour of the intervening country, and the intensity of the interference there will be a certain distance at which peaks of ignition noise become greater than the carrier. The irregularity and difficulty of reproduction of these disturbances require a different method of comparison which will be hereinafter described.

As the site at Westhampton, which was on a section of the beach remote from man-made static, was obviously too favorable a site, a new one was selected in Haddonfield, New Jersey, and about the end of June the receiving apparatus was moved there and erected at the home

of Harry Sadenwater. Haddonfield is located about eighty-five miles from New York in the vicinity of Camden, New Jersey, and is over 1000 feet below line of sight of the top of the Empire State Building in New York. Although the field strength at Haddonfield was considerably below that at Westhampton Beach, good reception was obtained almost immediately, the sole source of noise heard being ignition noise

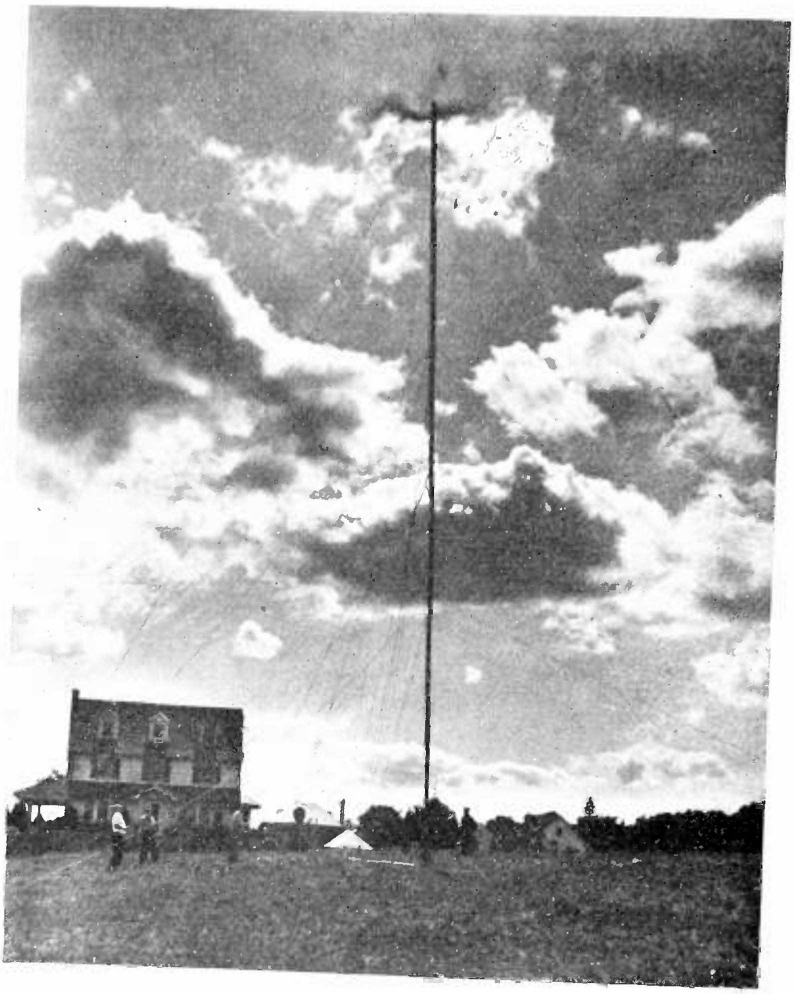


Fig. 24

from a few types of cars in the immediate vicinity of the antenna, or lightning striking within a few miles of the station. At this distance fading made its appearance for the first time, a rapid flutter varying in amplitude three- or four-to-one being frequently observable on the meters. The effect of it was not that of the selective fading so well known in present-day broadcasting. Very violent variations as indicated by the meters occurred without a trace of distortion being heard

in the speaker. During a period of over a year in which observations have been made at Haddonfield, but two short periods of fading have been observed where the signal sank to a level sufficient to bring in objectionable noise, one of these occurring prior to an insulation failure at the transmitter.

It is a curious fact that the distant fading, pronounced though it may be at times, is not so violent as that which may be encountered at a receiving station located within the city limits of New York. The effect, which appears to be caused by moving objects in the vicinity of the receiving antenna, causes fluctuations of great violence. In was apparently first observed by L. F. Jones of the RCA Manufacturing Company within a distance of half a mile of the Empire State transmitter. It occurs continually at Columbia University located about four miles from the Empire State transmitter but no injurious effect on the quality of transmission has ever been noted.

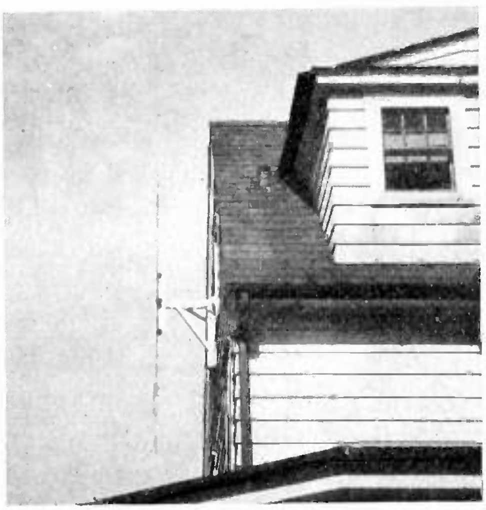


Fig. 25

While at first, because of the lower field strength at Haddonfield and the greater prevalence of ignition disturbances, the superiority over the regular broadcast service was not so marked as at Westhampton Beach, the subsequent improvements which were instituted at both transmitting and receiving ends of the circuit have more than offset the lower signal level. Some idea of their extent may be gained by comparison of the initial and final antenna structures. Fig. 24 shows the original antenna during course of erection, a sixty-five foot mast bearing in the direction of New York permitting the use of an eight-wave length sloping wire of very useful directive properties. Fig. 25

shows the final form on which the results are now much better than were originally obtained with the directional wire.

During the past summer, which was marked by thunderstorms of great severity in the vicinity of Philadelphia, it was the exception when it was agreeable or even possible to listen to the nightly programs of the regular broadcast service from the fifty-kilowatt New York stations. In some of the heaviest storms when lightning was striking within the immediate vicinity of the antenna, so close in fact that the lead-in was sparking to a near-by water pipe, perfectly understandable speech could be received on the frequency modulation system, although the disturbance was sufficient to cause annoyance on a musical program; but these periods seldom lasted more than fifteen minutes when the circuit would again become quiet. On numerous occasions the Empire State signal was better than that of the fifty-kilowatt Philadelphia station WCAU located at a distance of twenty miles from Haddonfield. Likewise during periods of severe selective side-band fading in the broadcast band which occurs even from station WJZ at Bound Brook, New Jersey, some sixty miles away, no signs of this difficulty would appear on the ultra-high-frequency wave.

Some of the changes which contributed to the improvement during the past year may be of interest. The introduction of the Thompson-Rose tube permitted the radio-frequency amplification required at forty-one megacycles to be accomplished with one stage and with considerable improvement of signal-to-noise ratio. It had a further interesting result. The tubes previously used for amplifying at this frequency were those developed by the Radio Corporation for the ultra-short-wave interisland communication system in the Hawaiian Islands. On account of the relatively low amplification factor of these tubes the shot effect in the plate circuit of the first tube exceeded the disturbances due to thermal agitation in the input circuit of that tube by a considerable amount. With the acorn type tube, however, the situation is reversed, the thermal noise contributing about seventy-five per cent of the rectified output voltage.

It should be noted here by those who may have occasion to make this measurement on a frequency modulation system that it cannot be made in the ordinary way by simply mis-tuning the input circuit to the first tube. To do so would remove the carrier from the current limiter and be followed by a roar of noise. The measurement must be made with a local signal of the proper strength introduced into one of the intermediate-frequency amplifiers. Under these conditions the antenna may be mis-tuned without interfering with the normal action of the limiter and the relative amounts of noise due to the two sources may readily be segregated.

Considerable trouble was caused during the early stages of the experiments by an order of the Federal Radio Commission requiring the changing of the frequency of the Empire State transmitter from forty-four to forty-one megacycles; this necessitating the realignment of the large number of interstage transformers in the modulating equipment shown in Fig. 20 and also the retermination of the antenna. It, however, led to the application of the idea inherent in superheterodyne design.

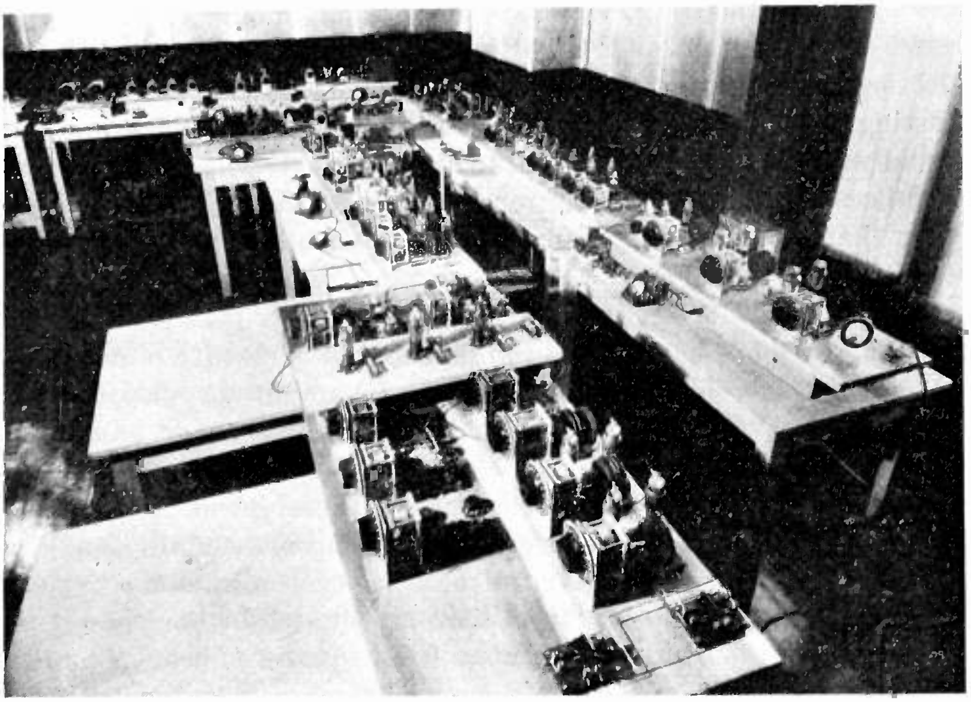


Fig. 26

While the circuits of the old modulator were temporarily modified and work carried on, a new modulation system was designed standardizing on an initial frequency of 100 kilocycles which was then multiplied by a series of doublers up to 12,800 kilocycles. By means of a local oscillator this frequency was heterodyned down to 1708 kilocycles, the new value of input frequency to the transmitter required to produce forty-one megacycles in the antenna. Any future changes in wave length can be made by merely changing the frequency of this second oscillator. The frequencies chosen were such that a deviation of 100 kilocycles could be obtained without difficulty, because of the extra number of frequency multiplications introduced. Fig. 26 shows the two modulation systems during the process of reconstruction with arrangements for making the necessary step-by-step comparisons between them.

Much attention was paid during the year to the frequency characteristic of the transmitter, which was made substantially flat from thirty to 20,000 cycles. This required careful attention to the characteristics of the doubler and amplifier circuits of the transmitter, and to John Evans of the RCA Manufacturing Company and to T. J. Buzalski I am indebted for its accomplishment. Continuous improvement of the transmitter and antenna efficiency was effected throughout the year, but of this phase of the development R. M. Morris of the National Broadcasting Company, under whose direction the work was carried on, is better qualified to speak. As the final step, the lines connecting the transmitter with the control board of the National Broadcasting Company at Radio City, from which the test programs were usually supplied, were equalized to about 13,000 cycles, and when this had been done the quality of reception at Haddonfield was far better than that obtainable from any of the regular broadcast stations.

Interference and Fading

Reference has heretofore been made to the difficulty of comparing the amounts of interference produced in amplitude and frequency modulation systems by the transient type of disturbance, particularly when, as in ignition noise, the peaks are greater in amplitude than the signal carrier. The best method of comparison seems to be that of observing how much greater signal level from the standard signal generator must be introduced into the receiving system when it is arranged to receive amplitude modulation than is required for the same signal-to-noise ratio on a frequency modulated system. The experimental procedure of making such comparison is to change the connection of the speaker rapidly from one receiver to the other, simultaneously changing the level of the local generator until the two disturbances as perceived by the ear are equal. At all times, of course, the amplification in the amplitude modulation receiver is correspondingly changed as the signal generator level is varied to apply the same voltage to the amplitude as to the frequency modulation detector so that the audio-frequency signal level which will be produced by the two systems is the same. The square of the ratio of the two voltages of the signal generator gives the factor by which the *carrier* power of the amplitude modulated transmitter must be increased to give equal performance. While the measurement is difficult to make, the following approximations may give some idea of the magnitudes involved.

If the peak voltage of the ignition noise is twice the carrier level of the frequency modulation system, about 150 to 200 times the power must be used in the carrier of the amplitude modulation system to

reduce the disturbance level to the same value. When the peak voltage is five times as great, about 35 to 40 times the power in the amplitude modulation carrier is sufficient to produce equality.[17] These observations have been checked aurally and by the oscilloscope. The results of measurements where the disturbances are due solely to the thermal and shot effects have been compared to those obtained with the method previously described and are found to check with it. The chief value of this method of measurement, however, lies in the ability to predict with certainty the signal level required to suppress all ignition noise. An experimental determination made at Haddonfield shows that a signal introduced from the local generator which produces at the current limiter ten times the voltage of the Empire State signal is sufficient to suppress the disturbance caused by the worst offender among the various cars tested. These cars were located as closely as possible to the doublet antenna shown in Fig. 25, the distance being about forty feet. The increase in field strength necessary to produce this result can be readily obtained by an increase in the transmitter power to twenty or twenty-five kilowatts and the use of a horizontally directional antenna array. An increase in the field strength of three or four to one by means of an array is within the bounds of engineering design so that the practical solution of the problem of this type of interference is certainly at hand up to distances of one hundred miles.

So also is the solution of the problem at its source. It has been determined experimentally that the introduction of 10,000 ohms (a value of resistance which is not injurious to motor performance) into the spark plug and distributor leads of the car referred to eliminates the interference with the Empire State signal.

Since active steps are now being taken by the manufacturers of motor cars to solve the more difficult general problem, the particular one of interference with sets located in the home will thus automatically disappear. The problem of eliminating the disturbance caused by an automobile ignition system in a receiving set whose antenna is a minimum of fifty feet away from the car is obviously a much simpler one than that of eliminating the interference in a receiver located in the car or in another car a few feet away.

During the course of the experimental work in the laboratory a very striking phenomenon was observed in the interference characteristics between frequency modulation systems operating within the same wave band. The immunity of a frequency modulation system from interference created by another frequency modulated transmission is of the

[17] Linear detection was used in the amplitude modulation receiver but no limiting was employed.

same order of magnitude as the immunity with regard to tube noises. This property merits the most careful study in the setting up of a broadcast system at those wave lengths at which the question of inter-station interference is a major factor. It is well known that when the carriers of two amplitude modulated transmitters are sufficiently close in frequency to produce an audible beat that the service range of each of them is limited to that distance at which the field strength of the distant station becomes approximately equal to one per cent of the field strength of the local station. As a consequence of this, the service area of each station is very greatly restricted; in fact the service area of the two combined is but a small percentage of the area which is rendered useless for that frequency due to the presence thereon of the two interfering stations. With the wide band frequency modulation system, however, interference between two transmissions does not appear until the field strength of the interfering station rises to a level in the vicinity of fifty per cent of the field strength of the local one. The reason for this lies in the fact, that while the interfering signal in beating with the current of the local station under such conditions may be producing a fifty per cent change in the voltage applied to the current limiter, the system is substantially immune to such variations in amplitude. The only way in which the interfering signal can make its presence manifest is by cross modulation of the frequency of the local signal. Since, under the conditions, this cross modulation produces less than a thirty-degree phase shift and since the characteristics of the wide band receiver are such that, at least within the range of good audibility, thousands of degrees of phase shift are necessary to produce full modulation, it is clear that a thirty-degree phase shift will not produce very much of a rectified output. For example, assuming two unmodulated carriers are being received, that their amplitudes have a ratio of two to one, and that their frequencies differ by 1000 cycles, then for a system having a wide band (of the order of 150,000 cycles) the modulation produced by the interaction of the two carriers would be of the order of one per cent of that produced by full modulation of the stronger carrier. This example, however, represents perhaps the worst possible condition as during modulation of either station, with the proper type of conversion system, the aural effect of the disturbance is greatly reduced. The whole problem of interference between unmodulated carriers may, however, be entirely avoided by separating them in frequency by an amount beyond the audible range. Hence it follows that with two wide band frequency modulated transmitters occupying the same frequency band that only the small area located midway between the two wherein the field strength of one station is less than

twice the field strength of the other will be rendered useless for reception of either station. This area may well be less than ten per cent of the total area. Even in this area reception may be effected as a receiving station located within it has only to erect directional aerials having a directivity of two to one to receive either station. The two-to-one ratio of field strength which has been referred to as the ratio at which interference appears is not by any means the limit but rather one which can be realized under practically all conditions. Better ratios than this have been observed, but the matter is not of any great importance since by the use of the directional antennas referred to it becomes possible to cover the sum of the areas which may be effectively covered by each station operating alone, subject only to the limitations of the noise level. The problem of the interference due to overlapping has been completely wiped out. One precaution only should be observed—the unmodulated carriers should be offset in frequency by an amount beyond the audible limit.

In the above analysis it has been assumed, of course, that the distance between stations has been selected so that the "no-mans land" between stations is not sufficiently distant from either one to be within the zone where any large amount of fading occurs. If the distance between stations is such that the signal strength varies appreciably with time then the directivity of the receiving antennas must be greater than two to one.

Difficulties and Precautions

The principles which have been described herein were successfully applied only after a long period of laboratory investigation in which a series of parasitic effects that prevented the operation of the system were isolated and suppressed. The more important of these effects, which will be of interest to those who may undertake work in this field, will be referred to briefly.

It was observed in the early work in the laboratory that it was at times impossible to secure a balance in the detector system, and that the amplitudes of the currents in the rectifiers varied in very erratic fashion as the frequency of the first heterodyne was changed. Under these conditions it was not possible to produce any appreciable noise suppression. The effect varied from day to day and the cause defied detection for a long period of time. Ultimately the presence of two side frequencies in the detector circuits was discovered, one of these frequencies lying above and the other below the unmodulated intermediate frequency by an amount equal to the initial crystal frequency of the transmitter. It was then discovered that the trouble had its

origin in the transmitting system and that a current having the fundamental frequency of the crystal, (in the present case 57.33 kilocycles), passed through the first doubler circuits in such phase relation to the doubled frequency as to modulate the doubled frequency at a rate corresponding to 57.33 kilocycles per second. This modulation of frequency then passed through all the transmitter doubler stages, increasing in extent with each frequency multiplication and appearing finally in the forty-four-megacycle output as a fifty-seven-kilocycle frequency modulation of considerable magnitude. In the first doubler tank circuit of the transmitter a very slight change in the adjustment of the tuning of the circuit produced a very great change in the magnitude of this effect. A few degrees shift in the tuning of the first doubler tank condenser, so small that an almost unnoticeable change in the plate current of the doubler occurred, would increase the degree of the modulation to such extent as to make the first upper and lower side frequencies in the forty-four-megacycle current greater than the carrier or mid-frequency current (when no audio modulation was applied). Under such conditions the proper functioning of the receiving system was impossible.

The delay in uncovering this trouble lay in the fact that it was obscured by the direct effect of harmonics from the transmitter doubler stages which had to be set up in an adjoining room and by the numerous beats which can occur in a double intermediate-frequency superheterodyne. To these effects were added an additional complication caused by the presence of harmonics in the circuits of the selective system resulting from the action of the limiter which the filtering arrangements did not entirely remove. The coincidence of one of these harmonics with the natural period of one of the inductances in the branch circuits likewise interfered with the effectiveness of the noise suppression. The causes of all these spurious effects were finally located and necessary steps taken to eliminate them.

With the removal of these troubles a new one of a different kind came to light, and for a time it appeared that there might be a very serious fundamental limitation in the phase shifting method of generating frequency modulation currents. There was found to be in the output of the transmitter at forty-four megacycles a frequency modulation which produced a noise in the receiver similar to the usual tube hiss. The origin of it was traced to the input of the first doubler or the output of the crystal oscillator where a small deviation of the initial frequency was produced by disturbances originating in these circuits. While the frequency shift in this stage must have been very small, yet on account of the great amount of frequency multiplication (of the order of 800

times) it became extremely annoying in the receiver; in fact for low levels of receiver noise that noise which originated in the transmitted wave was by far the worse. For a time it seemed as though the amount of frequency multiplication which could be used in the transmitter was limited by an inherent modulation of the frequency of the oscillator by disturbances arising in the tube itself. The proper proportioning of the constants of the circuits, however, reduced this type of disturbance to a point where it was no longer of importance and frequency multiplications as high as 10,000 have since been effectively used. On account of the very large amount of frequency multiplication, any troubles in these low-frequency circuits caused by noisy grid leaks, improper bypassing of power supply circuits, or reaction of one circuit upon another become very much more important than they would normally be. Difficulties of all these kinds were encountered, segregated, and eliminated.

Another source of trouble was discovered in the correction system. Because of the range in frequency required, particularly in multiplex work where thirty to 30,000 cycles was frequently used, the output voltage of the correction system at the higher frequencies became very much less than the input voltage, hence any leakage or feed-forward effect due to coupling through the power supply circuits developed a voltage across the output much higher than that required by the inverse frequency amplification factor as determined by the correction network. Hence, the frequency swing for the upper frequencies of modulation would frequently be several hundred per cent greater than it should be. Likewise, at the lower frequency end of the scale various reactions through the power supply were very troublesome. All these effects, however, were overcome and the correction system designed so that its accuracy was within a few per cent of the proper value.

From the foregoing it might be assumed that the transmitting and receiving apparatus of this system are inherently subject to so many new troubles and complications that their operation becomes impracticable for ordinary commercial applications. Such is not the case. The difficulties are simply those of design, not of operation. Once the proper precautions are taken in the original design these difficulties never occur, except as occasioned by mechanical or electrical failure of material. During the period of over a year in which the Empire State transmitter was operated, only two failures chargeable to the modulating system occurred. Both were caused by broken connections. Even the design problems are not serious as methods are now available for detecting the presence of any one of the troubles which have been here enumerated.

These troubles were serious only when unsegregated and en masse

they masked the true effects and made one wonder whether even the laws of electrical phenomena had not been temporarily suspended.

Multiplex Operation

During the past year, two systems of multiplexing have been operated successfully between New York and Haddenfield and it has been

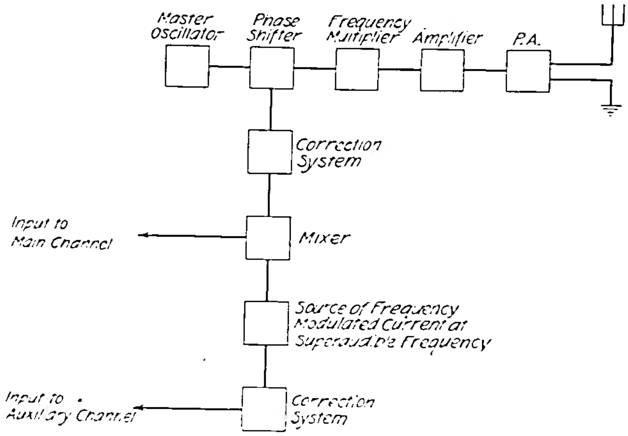


Fig. 27

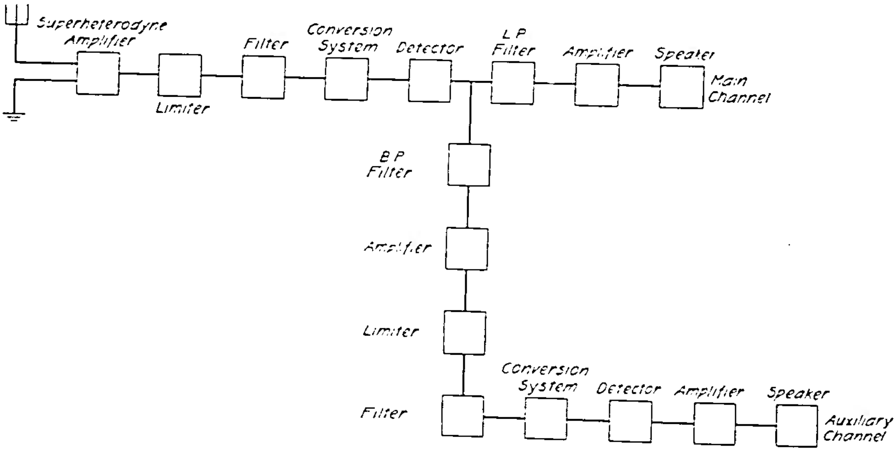


Fig. 28

found possible to transmit simultaneously the red and blue network programs of the National Broadcasting Company, or to transmit simultaneously on the two channels the same program. This last is much the simpler thing to accomplish as the cross-talk problem is not a serious one. The importance of multiplexing in point-to-point communication services has long been recognized. In broadcasting there are several applications which, while their practical application may be long deferred, are clearly within view.

Two general types of multiplexing were used. In one type a current of superaudible frequency is caused to modulate the frequency of the transmitted wave. The frequency at which the transmitted wave is caused to deviate is the frequency of this current and the extent of the deviation is varied in accordance with modulation of the amplitude of the superaudible frequency current. At the receiver detection is accom-

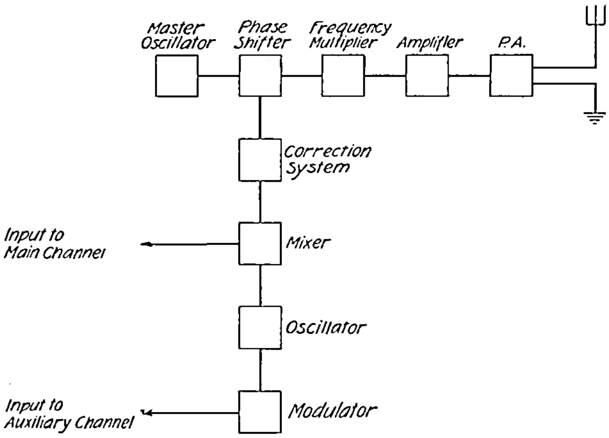


Fig. 29

plished by separating the superaudible current and its component modulations from the rectified audible frequency currents of the main channel and reproducing the original modulating current from them by a second rectification. The general outline of the system is illustrated in Figs. 27 and 28. The setting of the levels of the main and auxiliary channels must be made in this system of modulation with due regard

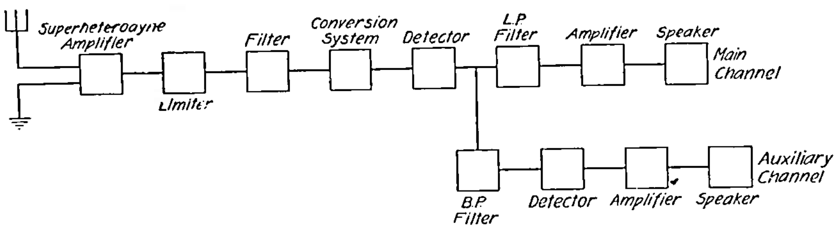


Fig. 30

to the fact that the deviation of the transmitted wave produced by the superaudible frequency current of the second channel is a variable one and changes between the limits of zero and double the unmodulated deviation.

In the second method of multiplexing a superaudible current produces a frequency modulation of the transmitted wave of constant deviation, the rate of the deviation being varied in accordance with the frequency of the superaudible current and modulation being produced

by varying the frequency of this auxiliary current and thereby the rate at which the superimposed modulation of frequency of the transmitted wave changes. The operations which must be carried out at the receiver are the following: After suitable amplification, limiting, and filtering, an initial conversion and rectification produces in the output of the detector the audible frequencies of the main channel and a superaudible constant amplitude variable frequency current. This last is selected by means of a band-pass filter, passed through a second con-

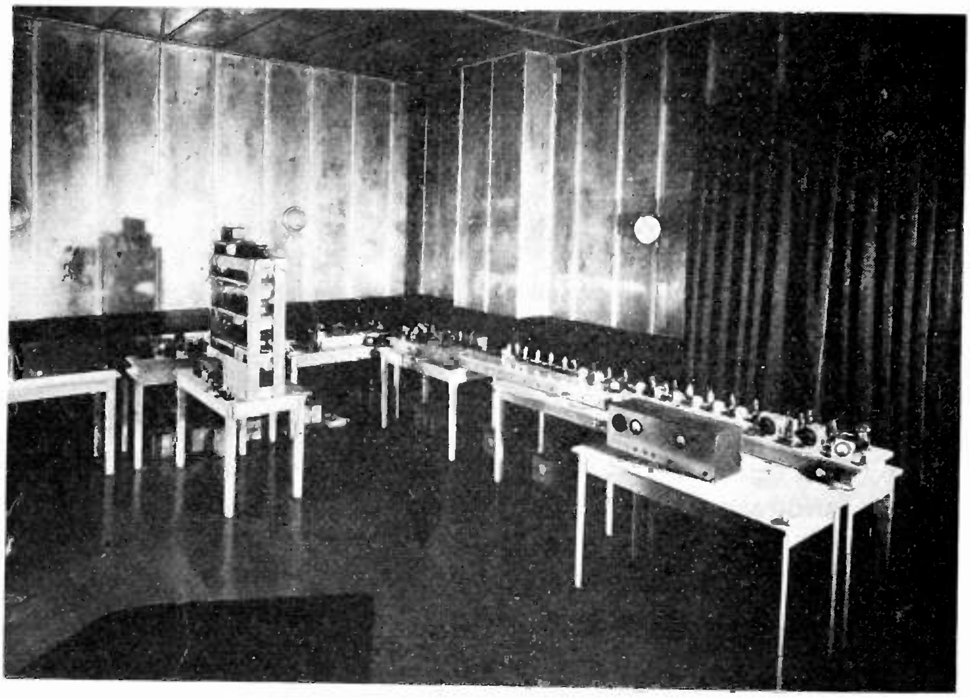


Fig. 31

version system to translate the changes in the frequency into variations of amplitude, and then rectified to recreate the initial modulating current of the auxiliary channel. The general arrangment of the system is illustrated in Figs. 29 and 30. This latter method of multiplexing has obvious advantages in the reduction of cross modulation between the channels and in the fact that the deviation of the transmitted wave produced by the second channel is constant in extent, an advantage being gained thereby which is somewhat akin to that obtained by frequency, as compared to amplitude, modulation in simplex operation. The subject of the behavior of these systems with respect to interference of various sorts is quite involved and will be reserved for future treatment as it is beyond the scope of the present paper.

The final arrangement of the modulating equipment installed at the Empire State station is illustrated in Figs. 31 and 32. The main channel apparatus is shown on the five tables located on the right side of the room. The vertical rack in the left center contains three channels for transmitting facsimile by means of the amplitude modulation method of multiplexing already described. In Fig. 32, located on the four tables on the left of the room is shown the auxiliary channel of the frequency modulation type already described. The comparatively

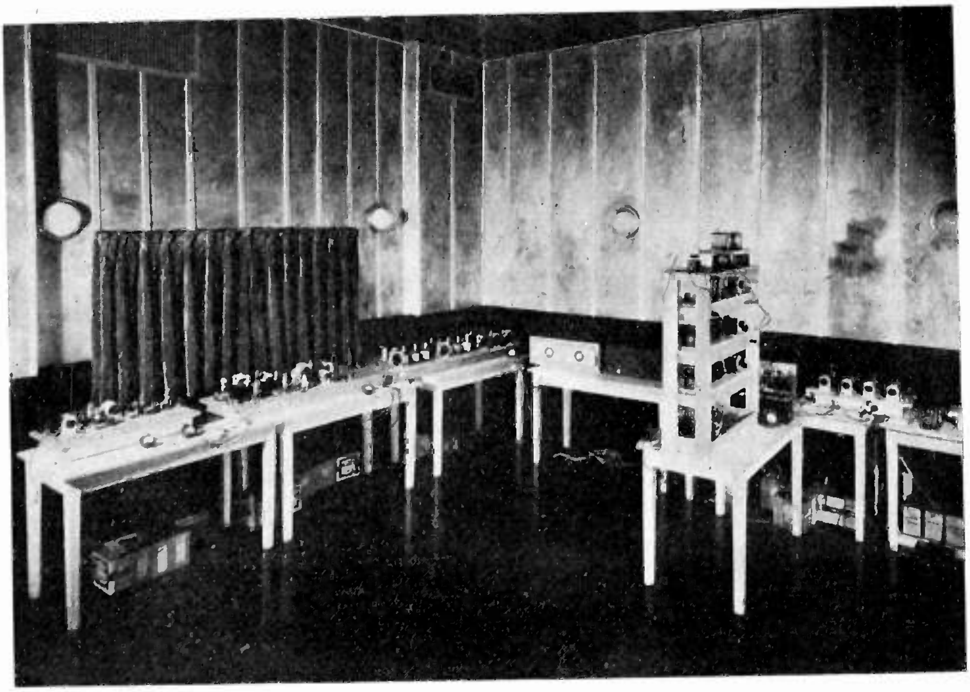


Fig. 32

low frequency of this channel was obtained by the regular method of phase shifting and frequency multiplication, the frequency multiplication being carried to a high order and the resultant frequency modulated current heterodyned down to twenty-five kilocycles (mid-frequency). A deviation up to ten kilocycles was obtainable at this frequency.

The receiving apparatus located at Haddonfield is illustrated in Figs. 33 and 34. Fig. 33 shows the modified Westhampton receiver and Fig. 34 the multiplex channels of the receiver. The vertical rack to the right holds a three-channel receiver of the amplitude modulation type. The two panels in the foreground constitute the frequency modulation type of auxiliary channel.

Some of the practical results may be of interest. It was suggested by C. J. Young of the RCA Manufacturing Company that it might be possible to transmit simultaneously a facsimile service at the same time that a high quality broadcast program was being transmitted. With the assistance of Mr. Young and Maurice Artzt this was accomplished

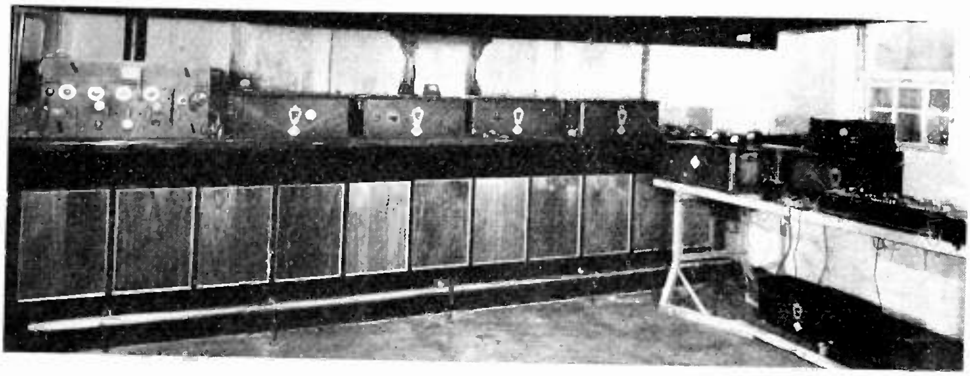


Fig. 33

over a year ago between New York and Haddonfield, New Jersey, the two services operating without interference or appreciable loss of efficiency at the distance involved. Two additional channels, a synchronizing channel for the facsimile and a telegraph channel, were also operated. The character of the transmission is illustrated in Fig.

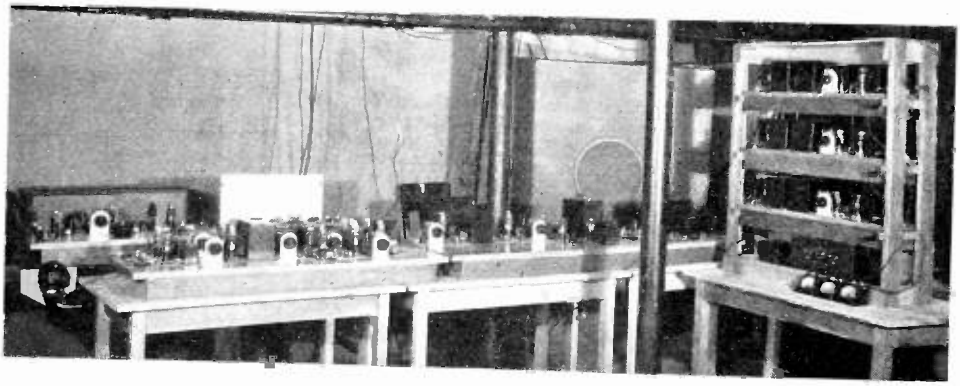


Fig. 34

35, which shows a section of the front page of the *New York Times*, This particular sheet was transmitted under considerable handicap at the transmitter as due to a failure of the antenna insulator on the forty-one-megacycle antenna it had become necessary to make use of the sixty-megacycle antenna for the forty-one-megacycle transmission. It is an interesting comment on the stability of the circuits that all four were kept in operation at the transmitter by one man, Mr. Buzalski,

New York Times.

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NEW YORK, SATURDAY, NOVEMBER 24, 1934. TWO CENTS

VANDERBILT WRIT CALLS ON CAREW TO DEFEND RULING

Definite Decision Is Sought on Habeas Corpus Action to Pave Way for Appeal.

GUARDIAN FIGHT RESUMED

Reply to Mother's Plea Asserts She Is Not Qualified to Fill Such a Position.

Mrs. Gloria Morgan Vanderbilt carried her efforts to obtain custody of her 10-year-old daughter, Gloria, to the Appellate Division yesterday, obtaining from Presiding Justice Edward R. Finch a show cause order in mandamus proceedings against Supreme Court Justice John F. Carew.

At the same time, Justice Carew's decision earlier this week, placing Gloria in custody of her aunt, Mrs. Harry Payne Whitney, for five days a week, was followed in Surrogate's Court by action bearing on the child's $2,800,000 estate. George W. Wickersham and Thomas B. Gilchrist, as co-guardians, opposed the plea of Mrs. Vanderbilt that she be made a guardian, also, of the estate.

After the show cause order had been signed by Presiding Justice Finch it was served upon Justice Carew in his chambers by Louis D. Frohlich, associate of Nathan Burkan, Mrs. Vanderbilt's counsel. The order directed the justice to show cause on Nov. 29 why he should not be required either to sustain or dismiss the writ of habeas corpus sought by Mrs. Vanderbilt in the Supreme Court ...

Clear Way for Appeal.

This was done, it was explained, to clear the way for an appeal from ...

SOVIET ARMY TO AID FRANCE IF INVADED, DEPUTIES ARE TOLD

Reporter of Budget Declares Russia Would Help Repel Any German Attack.

MILITARY FUNDS APPROVED

French War Minister Announces Term of Conscript Service Will Not Be Raised.

By P. J. PHILIP.
Wireless to The New York Times.

PARIS, Nov. 23.—An understanding by which Soviet Russia has offered her army to aid France in case of attack by Germany was reported in the Chamber of Deputies today by Leon Archimbaud, Reporter of the Budget.

In the course of the debate on the army appropriations, Deputy Archimbaud declared that he puts his hopes for the preservation of peace in a union of strength between France and Russia.

"Only that union," he said, "can stabilize Europe and peace. Russia has a solid, well-equipped army which she offers us in case of conflict with Germany. It may be regrettable that twenty years after the war we should come back to the old policy of a balance of power, but it is not our fault.

"It cannot be denied that an understanding exists between the two countries."

After the debate, it was declared in government circles that the Deputy was not speaking for the Cabinet, but was only expressing his idea of what Russia would be likely to do in case of German aggression against France. It was M. Archimbaud who, in his report of ...

U. S. AND BRITA[IN] AS NAVY TALKS JAPAN TO DEN[OUNCE]

PACT ASSAILED BY SAITO

Ambassador Says Tokyo Will End It No Matter What Occurs at London.

HOLDS HONOR IS AT STAKE

Tells Philadelphia Audience Ratios Show Japan Is Looked Down On as 'Spoiled Child.'

OPPOSES BUILDING RACE

Declares Tokyo Is Willing to Enter an Agreement to Guard Philippine Independence.

Text of the address by Ambassador Saito, Page 6.

Special to The New York Times.

PHILADELPHIA, Nov. 23.—So long as a navy retains its character as a "fighting unit" instead of becoming merely a "policing force," Japan cannot give up her claim for equality in naval strength, Ambassador Hiroshi Saito of Japan said here tonight in an address before the American Academy of Political ...

Japan's War[...] In a Long C[...]

TOKYO, Nov. [...] of the budget" [...] army and navy [...] teen-hour session [...] Cabinet.

Before the gov[...] to give three [...] than one billion [...] General Senjuro [...] of War, had thre[...] if his demands w[...] and Admiral Mine[...] ter of the Navy, [...] "the internationa[...] be considered."

In the end they [...] resistance of [...] Minister of Fi[...] tempted in vain [...] times approxima[...] limits of the curr[...]

Details of the de[...] were not revealed [...] demanded 771,800 [...] ships, 76,000,000 [...] tenance, 46,000,00[...] tion of warships [...] expansion and [...] the air force and [...] for new weapons [...]

Major army req[...] 000,000 yen for [...] munitions and 7[...] pansion of the ar[...]

HULL ENC[...] UNITY WIT[...]

Nov. 24, 1934

Four Channel Operation

\# (1) Music from chain

(2) Synchronizing channel

(3) Facsimile signal

(4) Telegraph channel

Empire State & Haddonfield N. J. W2XDG on 41 megacycles operating on 61 megacycle antenna.

Fig. 35

who was alone in the station on that day. The combined sound and facsimile transmission has been in successful operation for about a year, practically perfect copy being obtained throughout the period of the

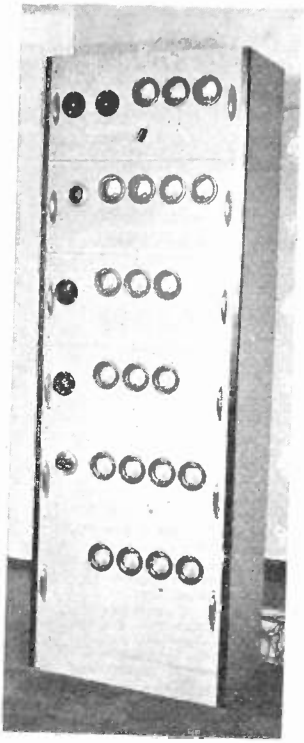

Fig. 36

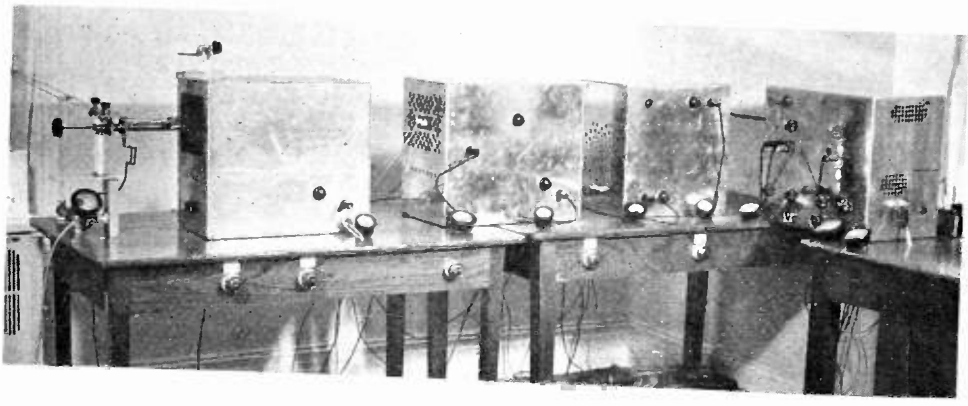

Fig. 37

severe atmospheric disturbances of the past Summer. The subject of this work and its possibilities can best be handled by Mr. Young, who is most familiar with it.

Acknowledgment

On account of the ramifications into which this development entered with the commencement of the field tests many men assisted in this work. To some reference has already been made.

I want to make further acknowledgment and express my indebtedness as follows:

To the staff of the National Broadcasting Company's station W2XDG for their help in the long series of field tests and the conducting of a large number of demonstrations, many of great complexity, without the occurrence of a single failure;

To Mr. Harry Sadenwater of the RCA Manufacturing Company for the facilities which made possible the Haddonfield tests and for his help with the signal-to-noise ratio measurements herein recorded;

To Mr. Wendell Carlson for the design of many of the transformers used in the modulating equipment;

To Mr. M. C. Eatsel and Mr. O. B. Gunby of the RCA Manufacturing Company for the sound film records showing the comparison, at Haddonfield, of the Empire State transmission with that of the regular broadcast service furnished by the New York stations;

To Mr. C. R. Runyon for his development of the two-and-one-half-meter transmitters and for the solution of the many difficult problems involved in the application of these principles of modulation thereto;

To Mr. T. J. Styles and particularly to Mr. J. F. Shaughnessy, my assistants, whose help during the many years devoted to this research has been invaluable.

Conclusion

The conclusion is inescapable that it is technically possible to furnish a broadcast service over the primary areas of the stations of the present-day broadcast system which is very greatly superior to that now rendered by these stations. This superiority will increase as methods of dealing with ignition noise, either at its souree or at the receiver, are improved.

Appendix

Since the work which has been reported in this paper on forty-one megacycles was completed attention has been paid to higher frequencies. On the occasion of the delivery of the paper a demonstration of transmission on 110 megacycles from Yonkers to the Engineering Societies Building in New York City was given by C. R. Runyon, who described over the circuit the transmitting apparatus which was used. A brief description of this transmitter is reproduced here.

The power delivered to the antenna was approximately 100 watts at 110 megacycles and the deviation (one half total swing) used during the demonstration was under 100 kilocycles. Fig. 36 illustrates the modulating equipment for this transmitter and the low power frequency multiplication stages. Fig. 37 shows the higher power frequency multiplier and power amplifier stages of the transmitter.

The rack shown in Fig. 36 consists of six panels. Panel number one at the top contains the correction system. Panel number two contains the master oscillator of 100 kilocycles and the modulator circuits. Panel number three contains a pair of doublers for multiplying the 100-kilocycle frequency to 400 kilocycles and the necessary filtering means for avoiding the modulation of the currents in the succeeding doubler stages by the 100-kilocycle oscillator current. Panel number four contains the doubling apparatus for raising the frequency to 3200 kilocycle and panel number five the multipliers for raising it to 12,800 kilocycles. Panel number five also contains a heterodyning and conversion system for beating the 12,800 kilocycles down to 2292 kilocycles. Panel number six contains a doubler for raising this to 4584 kilocycles and an amplifier for increasing the level sufficiently to drive the succeeding power stage. The output of this amplifier is fed through a transmission line to the metal box at the extreme right of Fig. 36 which contains a series of doublers and amplifiers for increasing the level and raising the frequency to 36,672 kilocycles. Adjacent to this box is a second box which contains a fifty-watt amplifier. This amplifier drives a tripler located in the third box and the tripler in turn drives the power amplifier located at the extreme left at 110 megacycles. The transmitter circuits were designed for total frequency swing of 500 kilocycles and may be effectively so operated. Because of the limitation of the receiver available at that time the demonstration was carried out with a swing of 200 kilocycles.

Proceedings of the Institute of Radio Engineers
Volume 24, Number 5 *May, 1936*

TELEVISION IN GERMANY*

By

HUBERT GIBAS

(N. V. van der Heem and Bloemsma, The Hague, Holland)

Summary—*This paper gives the status of television in Germany in the autumn of 1935. The systems used for transmission and reception of television are described. The subject of image quality and the possibilities of improvement, together with the prospects of television, are discussed.*

BERLIN'S first television transmitter was erected at the beginning of 1935 for the purpose of transmitting television program material. Two transmitters are used, one for the picture and the other for the sound. The antennas are located at the top of the broadcast tower in Witzleben, Berlin. The transmission is primarily from sound film, but there is some transmission from the studio. The

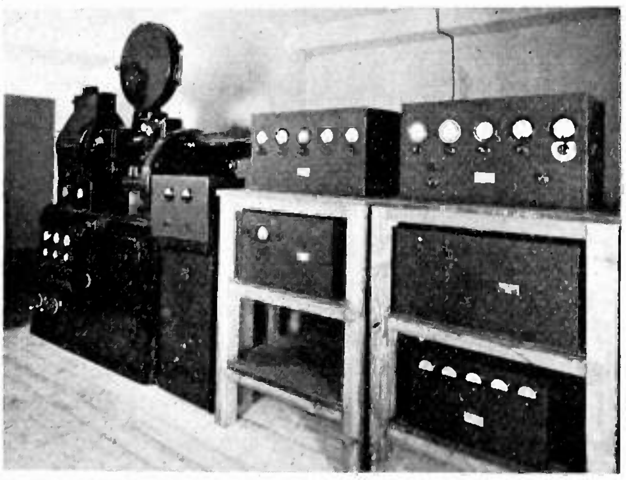

Fig. 1—Fernseh-A-G film transmitter.

intermediate film system is also used, in which case the image to be transmitted is first photographed on a film, which also carries sound. The film is then developed, fixed, washed, dried, and transmitted within one minute.

The Fernseh-A-G's film transmitter is shown in Fig. 1. The image to be transmitted is dissected by a Nipkow disk which runs in a vacuum. This provides a dust-free space for the disk and also reduces the required driving power.

* Decimal classification: R583. Original manuscript received by the Institute, November 1, 1935.

The range of the radio transmitter is a little more than the optical range, say about 100 kilometers. However, the distance depends on the location of the receiver so that very good reception from Berlin is obtained on the top of the Brocken, which is 1100 meters higher than Berlin. The distance in this case is 200 kilometers. In Neuruppin, seventy kilometers from Berlin, is located a very satisfactory receiving station. To cover a portion of Germany with television a network of about twenty-five transmitters has been planned.

The most important firms engaged in television in Germany are Fernseh-Aktiengesellschaft, Berlin—Zehlendorf; Radioaktiengesell-

Fig. 2—Manfred von Ardenne with his television equipment.

schaft, D. S. Loewe, Berlin—Steglitz; Lorenz-Aktiengesellschaft, Berlin—Tempelhof; C. F. H. Müller Aktiengesellschaft, Hamburg; Tekade, Nürnberg; and Telefunken Aktiengesellschaft, Berlin SW 11.

All of these, except Tekade, employ the cathode-ray tube at the receiver. Fig. 2 shows a picture of Manfred von Ardenne seated near his television equipment. He is well known in Germany for his cathode-ray tube work. His book "Fernseh-Empfang" gives his latest results in television reception, as well as details concerning receivers and accessories.

The elements of a cathode-ray tube manufactured by Leybold and von Ardenne, Köln-Bayenthal, are shown in Fig. 3. Two pairs of plates are provided for horizontal and vertical electrostatic deflection. Some cathode-ray tubes use only one pair of plates in combination with magnetic deflecting in one direction. For such a combination the length of the tube becomes shorter. The operation of cathode-ray tubes is well known and will not be discussed here.

Tekade uses a mirror-screw to reproduce the image at the receiver. This is shown in Fig. 4. The number of mirrors equals the number of

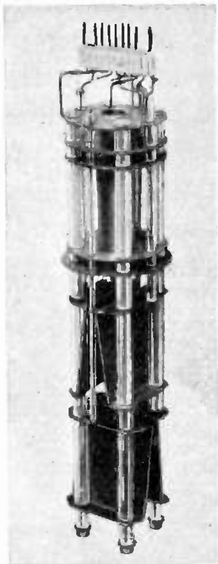

Fig. 3—Leybold and von Ardenne cathode-ray tube elements.

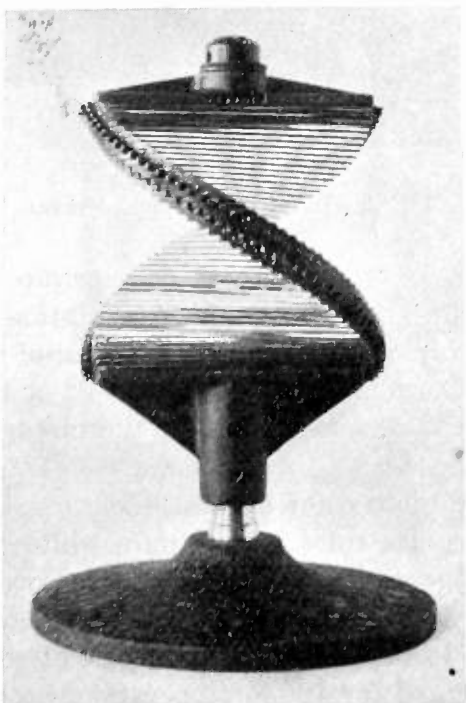

Fig. 4—Tekade mirror-screw.

lines in which the image is divided. To control the light intensity a Kerr cell is employed. The advantages of this arrangement are that no parts

need be renewed from time to time, and possibly the advantage of cost over cathode-ray tube receivers. Cathode-ray tubes, in the thirty-centimeter diameter size, cost about RM. 300. No deflecting voltage supply or other equipment, including a source of high voltage, is necessary with the Tekade system. On the other hand, it is necessary to have a synchronous motor to turn the mirror-screw.

Television receiver production has proceeded to the point where large scale production is practicable. Figs. 5, 6, and 7 illustrate some of the receivers. Up to a year ago the number of control knobs was as great as twelve. These have now been reduced to not more than four,

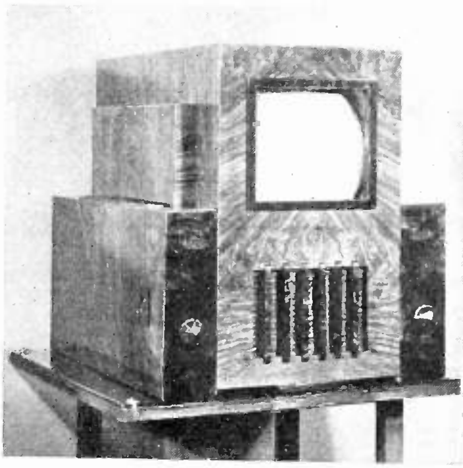

Fig. 5—Loewe television receiver.

so that the average person can tune and operate the receivers. The present controls are: receiver tuning, regulation of light intensity (background control), volume and tone control of the sound receiver. It is planned in Germany to standardize on a constant frequency difference between the carrier waves of the picture and sound transmitters.

The size of the picture for normal home use is about twenty by twenty centimeters. Its color is now pure white—a year ago it was yellow. The brightness of the image has been considerably improved and is now about five times as great as a year ago. The pictures are sufficiently bright to be visible in slightly reduced daylight. The receivers, while designed for 180-line operation, are so built that they can be changed with slight alterations to receive 240 lines. The synchronizing is automatic. The tone quality of the sound is excellent because higher modulation frequencies are not cut off by too great selectivity, as must happen in the regular broadcast bands.

The television receiver manufactured by Loewe is shown in Fig. 5. Under the cathode-ray tube is the loud speaker, right and left are two double control knobs for receiver tuning, light intensity, volume, and tone control.

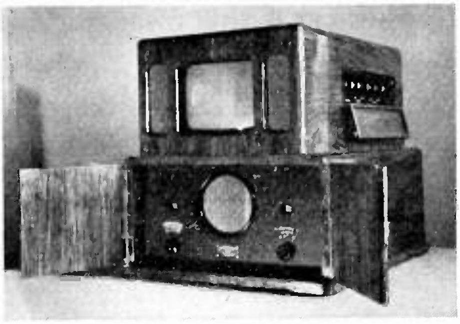

Fig. 6—Fernseh-A-G television receiver.

The receiver produced by Fernseh-A-G is shown in Fig. 6. The knobs shown in a row on the right-hand side are for adjustment of the position and sharpness of the image, as well as light intensity. They are adjusted once and then remain set. At the rear of the receiver are terminals for antenna, ground, and power.

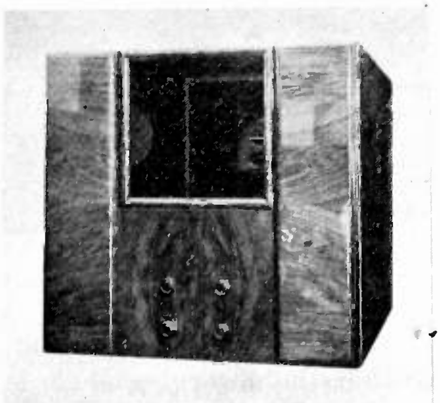

Fig. 7—Tekade television receiver.

The Tekade television receiver is illustrated in Fig. 7. The mirror-screw is visible in the background of the shadow box, on the left of which can be seen a portion of the loud speaker. The control units in this case are for tuning the picture, the sound, and also for volume and light intensity. Tekade uses an incandescent lamp having a long incandescent wire as a light source. The light passes through the Kerr

cell, with which are associated two prisms. Such a light controlling system is well known. The focusing of the light controlling equipment is carried out at the factory and must not be altered. Previously the mirror-screw system had the disadvantage that the picture was visible over a restricted angle, so that the observer had to be on its center line. With the so-called optical grid this disadvantage disappeared. This grid consists of a small glass vessel, in which are thin glass sticks, one above the other, surrounded by a fluid. In this way the light

Fig. 8—Telefunken television receiver.

beam is directed in a vertical direction and the image appears to be essentially longer, so that the observing angle is considerably larger. The size of image produced by this system can be enlarged rather simply, a feature that is not possible in ordinary cathode-ray tubes. If an arc light is used as a light source there is sufficient light for an image of large size.

Fig. 8 is a rear view of a Telefunken receiver.

The Loewe receiver without its cabinet is shown in Fig. 9. The parts of this receiver are the picture receiver, sound receiver, scanning voltage supply unit, cathode-ray tube, loud speaker, and voltage source.

In some television receivers the first radio-frequency stages of the television and sound receivers are combined. The picture receiver must have a communication band width of about one megacycle for an image of 180 lines, with each line having 240 image points, and at a picture repetition rate of twenty-five pictures per second.

We now come to the subject of synchronization. The carrier which is modulated by the picture is interrupted twenty-five times a second. The duration of each interruption is five per cent of the transmitting time for one picture. During this interruption the electron beam at the receiver must return from the bottom of the image to the top. The

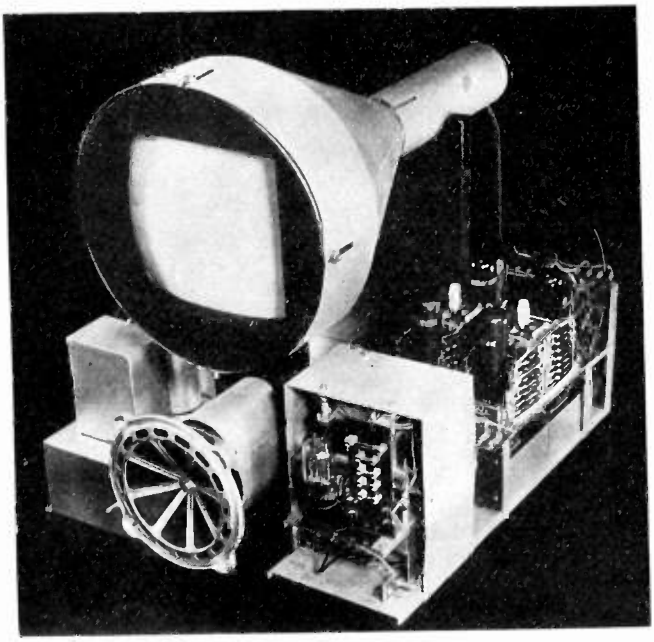

Fig. 9—Loewe television receiver, removed from cabinet.

carrier wave is also interrupted 180 times per image. During these interruptions the electron beam must return from the end of one line to the beginning of the next. The interruption time in this case is about five per cent of the transmitting time for one line. During the interruptions the electron beam is not visible. These interruptions form the synchronizing impulses for the scanning oscillators at twenty-five images per second and 180 lines per image.

Most of the deflecting apparatus uses gas-filled tubes as generators. The scanning voltages in some cases must be amplified before use. The cathode-ray tubes are surrounded by metallic screens to avoid disturbances from outside. The placing of the components in the cabinet must be carefully carried out. The high voltage for the cathode-ray

tube is about 4000 volts. Most of the receivers use a special antenna which can be placed anywhere in the room. If, however, the receiver is at some distance from the transmitter the antenna must be located in or near the optical path of the transmitter.

The quality of the reproduced pictures can be judged by Fig. 10. This is an unretouched photograph of the announcer at the television transmitter in Berlin. At present television images in Germany have two difficulties. First, the image flickers so that the eyes of the observer are soon tired, and second, 180-line detail is not sufficient. Many efforts are being made to eliminate these troubles. To provide more detail it is intended to use 240 lines. The Fernseh-A-G has made experiments with 320 lines.

Fig. 10—Unretouched photograph of television image. Von Ardenne and Lorenz.

For the elimination of flicker there are two possibilities; first, the speeding up of the number of pictures per second. Thirty-five images per second have been tried, in which case no flicker was visible, but this would not be true if more brightness were available. The greater the light intensity the greater the flicker. When transmitting more than twenty-five images per second normal sound films, of course, cannot be used. Then too, the modulation frequency bands are still wider because there are more picture elements per second to be transmitted.

The second possibility of flicker elimination is the so-called "line-jump" system. Two German manufacturers, Loewe and Tekade, have demonstrated this. The principle is as follows: Suppose we have a 180-line picture, twenty-five frames per second. Now if the 1st, 3rd, 5th . . . etc., lines be transmitted during the first half of the 25th of a second interval, and then the 2nd, 4th, 6th, . . . etc., line be transmitted in the second half of the picture interval, it means that the two complete

pictures are shown displaced by the width of one line. This gives the eye the same impression as though fifty images per second were transmitted. Under these conditions the picture is entirely free of flicker.

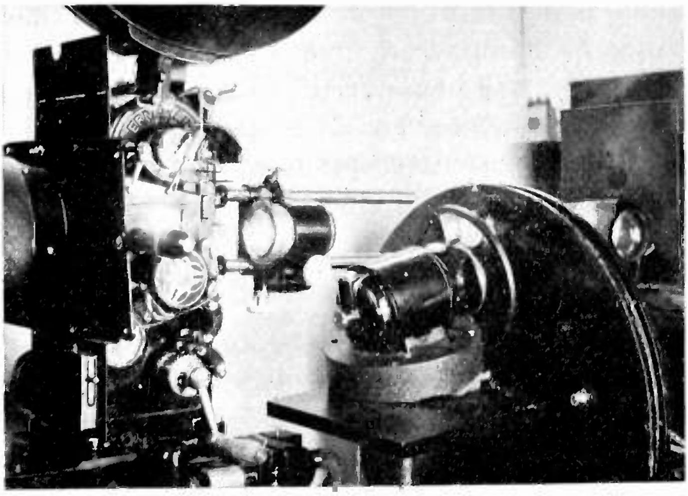

Fig. 11—Tekade film scanning equipment for interlaced pictures.

For such an interlacing system Tekade uses a small disk placed between the film and the Nipkow disk, as seen in Fig. 11. This disk, with its motor, is shown in Fig. 12. The disk has glass in one half and air in

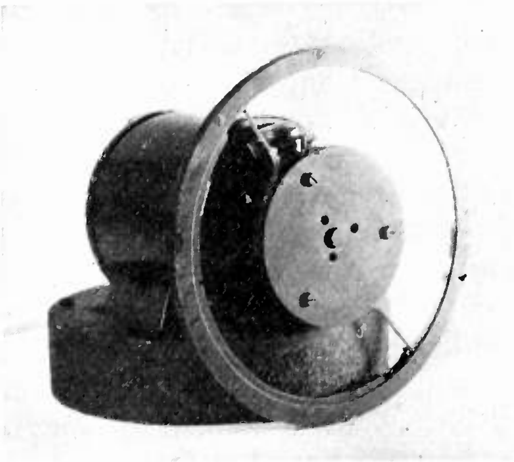

Fig. 12—Tekade disk used in connection with interlaced film scanning.

the other half. For 180 lines the Nipkow disk has ninety holes and makes two revolutions per image. During the first revolution the air space of the small disk is between the film and the Nipkow disk. Dur-

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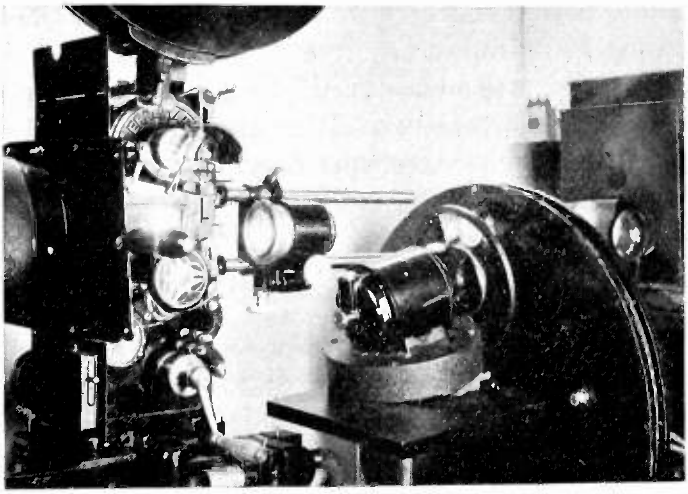

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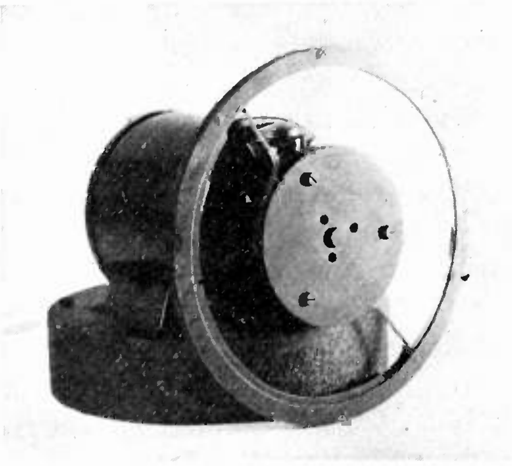

Fig. 12—Tekade disk used in connection with interlaced film scanning.

the other half. For 180 lines the Nipkow disk has ninety holes and makes two revolutions per image. During the first revolution the air space of the small disk is between the film and the Nipkow disk. Dur-

ing the second revolution the glass is in place. The glass breaks up the light beam in such a manner as to shift it by the width of one line.

Looking into the future we see that before very long Germany will have a television system which will meet the highest requirements, about the same as that to which we are accustomed in cinema theatres. If it is possible to manufacture great numbers of television receivers the price, of course, will be reduced then many more people will be able to buy television receivers. It is quite possible, therefore, that within ten years television reception will be as prevalent as sound broadcast reception is now.

Proceedings of the Institute of Radio Engineers
Volume 24, Number 5 May, 1936

A NEW SYSTEM FOR BLIND LANDING OF AIRPLANES*

By

K. BAUMANN AND A. ETTINGER
(Basel, Switzerland)

Summary—*A method for blind landing of airplanes which differs from the systems used heretofore by great simplification of the equipment, is described. In addition it makes possible the control of the landing maneuvers from the ground. The advantages of the new method are discussed.*

INTRODUCTION

In order to make a blind landing, the pilot must know the landing direction, the beginning point of the landing, and the proper glide path for the field. The problem has already been treated in various ways and practical solutions for it already exist. Individual methods merely confine themselves to the solution of a part of the problem. Thus, for example, only the entrance direction and, through the main signal, the moment for beginning the landing, are transmitted by the long-wave beacon developed by Philips. Conditions are similar in the blind landing method of the Army Air Corps, used by the Bureau of Air Commerce. In these methods, the pilot must depend upon his mechanical blind flight instruments, chiefly on the directional gyroscope, during the actual landing itself.

The most complete system which rests entirely upon a radioelectrical basis is that developed by Dunmore and Diamond in the Bureau of Standards. It gives the beginning point of the landing and the vertical glide path, as well as the runway direction.

Lorenz's system which likewise transmits all the data necessary for blind landings, should also be noted. For fixing the runway direction and the glide path, it uses a single transmitting aerial system, the horizontal characteristic of which defines the runway direction and the vertical characteristic, the glide path. An initial signal gives the starting point of the landing.

In all these systems the landing direction and the glide path are defined through the horizontal and vertical characteristics of an arrangement of transmitting aerials erected on the ground. The signals sent out by these systems are received in the airplane and there made audible or visible.

* Decimal classification: R528. Original manuscript received by the Institute, August 9, 1935; translation received by the Institute, September 10, 1935.

Description of the New System

For reasons which are set forth in the next section, the usual methods were abandoned in the new system developed by the authors. Instead of transmitting aerials fixing the direction and glide path, there are directionally sensitive receiving aerials. The complete installation is best explained by means of Fig. 1.

In the airplane there is an ultra-short-wave transmitter 1. In the experimental model which we built this is a crystal controlled transmitter which works at a frequency of 345,252 kilocycles. The final stage has a carrier output of about ten watts and is completely modulated by a tone generator. A horizontal dipole antenna placed above the upper wings of the airplane is fed by this transmitter through a power line. This transmitter 1 sends out a continuous dash modulated with constant frequency and amplitude.

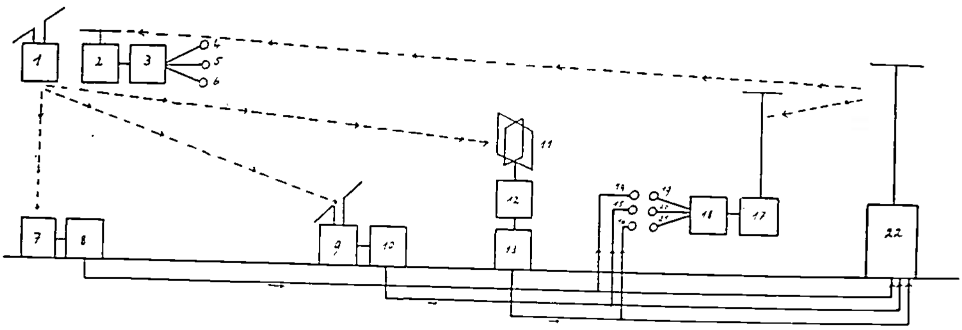

Fig. 1

To determine the landing direction, the receiving characteristics of two crossed loops, 11, are used. These loops are alternately connected to the receiver 13 through a relay 12 in such a way that the period of connection of one loop is longer than that of the other. If the airplane is flying in the direction that bisects the angle between the two loops, no abrupt change in loudness occurs in the output of receiver 13 when the coils are switched in. A continuous dash is heard. If the airplane deviates from the exact runway direction, either the longer or shorter signal will become louder, so that the side deviation from the correct course can be discerned. The airport transmitter 22, which operates on a long wave of 350 kilocycles, is modulated with the low-frequency output of receiver 13. Depending upon whether the airplane moves in the direction halfway between the loops or not, the degree of modulation of the airport transmitter remains constant or the longer or shorter signals become more strongly modulated when the loops are reversed. These modulated signals sent from the long-wave transmitter

are received in the airplane through the standard long-wave receiver 2 and conducted to an indicator 4, which gives information of any deviation from the course and an indication of the side. This is, therefore, a matter of automatic return signaling of the course fixed through loops 11.

The determination of the vertical glide path occurs simultaneously according to the same principle. In the experimental installation the vertical characteristic of a horizontal receiving dipole was used for this. In Fig. 1, the receiver connected to this dipole is seen at 9. The output of this receiver, again rectified, also controls the amplitude of a tone generator 10, the frequency of which differs from the modulating frequency of the ultra-short-wave transmitter 1. According as the airplane moves on a level suitable as a glide path or not, the output of receiver 9, and with it the amplitude of the controlled tone generator 10, remains constant or becomes greater with a deviation upward, or smaller with a downward one. This tone of generator 10, fluctuating in amplitude according to the position of the airplane with relation to the level, also modulates the airport transmitter, but with a different frequency than that which serves to fix the runway direction. These signals are also received in the airplane through receiver 2, simultaneously on the same carrier with the return signals for horizontal navigation, and carried to instrument 5 through a wave-band filter 3, which separates the different modulating tones of the airport transmitter from one another. During landing the deflection of this instrument must remain constant.

The beginning point of the landing is determined through receiver 7, which is connected to an aerial arrangement with an upward directed receiving diagram. When flying over this point a sound generator 8, which has a different frequency from generator 10 and the modulating tone of transmitter 1, and goes to transmitter 22 as a third modulating tone, is switched in through receiver 7 for a short time. It is also received by the airplane through receiver 2 and carried over filter 3 to a discharge glow lamp 6, which lights up when the entrance signal is flown over and fixes the beginning of the landing.

As the distance from the airport operating transmitter changes continuously during landing, receiver 2 must have an automatic volume compensation, so that the amplitude of the return pilot signals will depend only on the degree of modulation of transmitter 22 and not on the absolute value of its carrier. The magnitude of the regulating voltage can be used in the well-known way, as a crude indication of the distance of the field. This can also be effected with the low-frequency signal voltage carried to instrument 4.

Advantages of the New System

With all previous systems for blind landing, it has not been possible to follow the landing procedure on the ground. The pilot has been entirely dependent upon himself and his instruments during the landing, and has not had sufficient control over the apparatus. The arrangement described makes this control possible without further ceremony. The output from the transmitters for the entrance signal and for vertical and horizontal navigation is carried on the ground, as in Fig. 1, to three instruments, 14, 15, and 16, which correspond to instruments 4, 5, and 6 in the airplane. From their position, the horizontal and vertical situation of the airplane is directly apparent. In addition, the return signaling to the airplane is also controllable with a standard long-wave transmitter 17 and the accompanying wave-band filter 18 to instruments 19, 20, and 21. These possibilities increase the operating safety of the plant very noticeably. Especially, they mean an important lessening of the load on the pilot.

Since the modulating tones emitted by the airport operating transmitter for return signaling to the airplane may all lie below 100 cycles, it is possible without further ado to send telephonic warnings or directions to the airplane during the landing over transmitter 22, by switching in a high-pass filter.

A further advantage consists in the fact that reception in the airplane is only on long waves. Effective prevention of engine troubles is much more easily carried out with these waves than with ultra-short waves. In addition, the signals of the airport operating transmitter are extraordinarily strong in the neighborhood of the field, so that operating safety is increased thereby. The power of the ultra-short-wave transmitter in the airplane can be kept very low, as the sensitivity of the ground receiver, which is no longer in the range of interference of the engine, can be made very high.

The easy transportability of the ground receiver may be important for many purposes. The receiver for entrance signals, and horizontal and vertical navigation may be set up, according to the direction of the wind, at places previously selected for this.

Proceedings of the Institute of Radio Engineers
Volume 24, Number 5 *May, 1936*

AN URBAN FIELD STRENGTH SURVEY AT THIRTY AND ONE HUNDRED MEGACYCLES*

By

R. S. Holmes and A. H. Turner
(RCA Manufacturing Company, Inc., Camden, New Jersey)

Summary—*A description is given of the transmitter and receiver equipment used in making field strength surveys in the Camden-Philadelphia area for a low power transmitter whose antenna is 200 feet above the ground, at frequencies of thirty and one hundred megacycles.*

Field strength contour maps for the area within approximately ten miles of the transmitter are given. From these maps the average field strength obtained at various distances from the transmitter was determined, and the attenuation of the signal was found to be proportional to the 1.84 power of the distance for thirty megacycles and the 2.5 power of the distance for one hundred megacycles for the region between one and ten miles from the transmitter.

Curves showing the variation from the average field strength of the signal along three routes radiating fifteen miles from the transmitter are given, and these variations are compared with the elevation profiles of the respective routes. It is shown that the signal is usually strongest on the brows of hills facing the transmitter.

Measurements were made in three representative residences, and from these data, curves showing the power required at the transmitter to furnish one hundred microvolts input to receivers with short indoor antennas located in houses at various distances up to ten miles from the transmitter were computed for the two frequencies.

THIS paper describes a survey made in the Camden-Philadelphia area of the field strength from an ultra-high-frequency transmitter operated at thirty and at one hundred megacycles. The survey was made during the Summer of 1934.

Measuring Equipment and Procedure

The signal for the survey was radiated from an antenna located on the roof of an RCA Manufacturing Company building located at Front and Cooper Streets, in Camden. The ground elevation at this point is about ten feet above sea level, and the center of the antenna was approximately 200 feet above sea level. This antenna, constructed as shown on Fig. 1, was of the same general type as that described by Kell.[1] An iron and duraluminum pole, grounded to the metal roof, served as antenna, support, and one side of the feeder line. The other side of the feeder line was spaced out from the pole, and was slidable

* Decimal classification: R270. Original manuscript received by the Institute, April 8, 1935; revised manuscript received by the Institute, August 16, 1935.

[1] Kell, Bedford, and Trainer, "An experimental television system," Proc. I.R.E., vol. 22, pp. 1260–1261; November, (1934).

through the standoff insulators, by means of the rope and pulley; this line could be raised and lowered to expose more or less of the top of the pole for radiation, for adjusting to the operating frequency.

In order to measure the antenna current, for computing the radiated power, a substitute antenna, located as shown in Fig. 1, was used. The horizontal substitute antenna was far enough from the roof so that

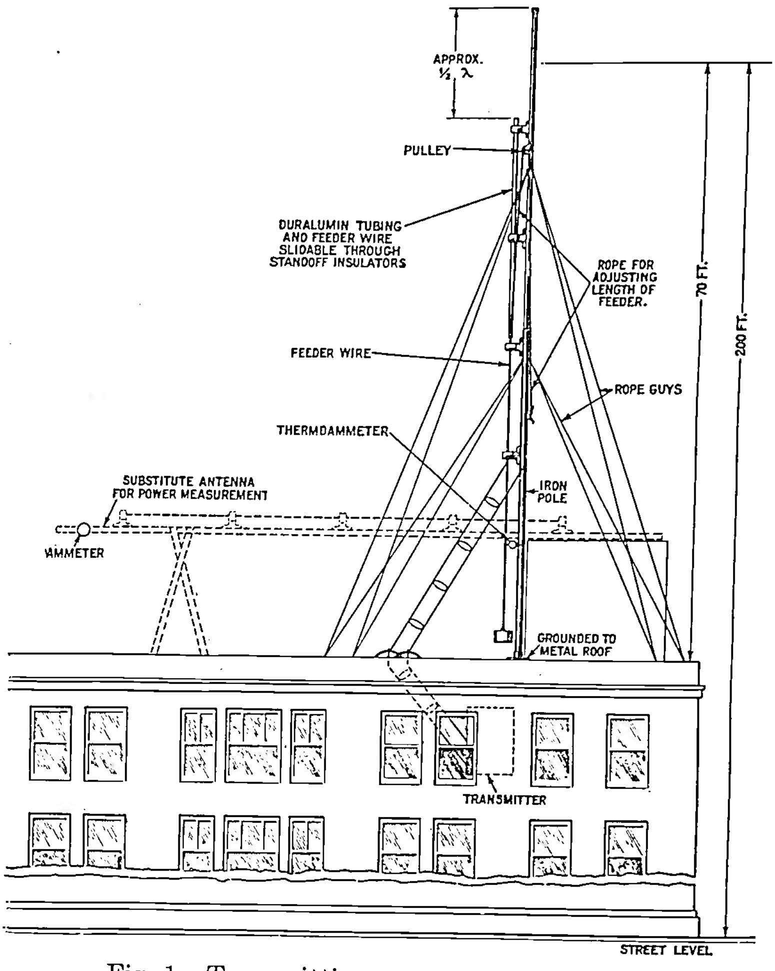

Fig. 1—Transmitting antenna arrangement.

the radiation resistance was not materially different from that of the vertical antenna. The current in the center of the vertical antenna was assumed to be the same as that in the substitute antenna when the feeder current was the same. The feeder current was maintained constant during all measurements at each frequency.

A further check of the radiated power was made by measuring the field intensity on the roof of a near-by brick tower at approximately the same elevation as the radiating portion of the vertical antenna. The

distance between the transmitter and the receiver was only slightly more than twice the elevation of each above the ground, and was partly occupied by several buildings having lower roof elevations. Under these conditions reflection was probably negligible, and was neglected in the calculation of radiated power from these field intensity measurements. The receiver indicated twenty per cent more field intensity at one hundred megacycles, and two per cent more at thirty megacycles, than should be produced by the current measured in the horizontal antenna and assumed to be the same in the vertical antenna. The radiated power is assumed to be that calculated from the antenna current, and all the data in this paper have been adjusted to one kilowatt radiated power.

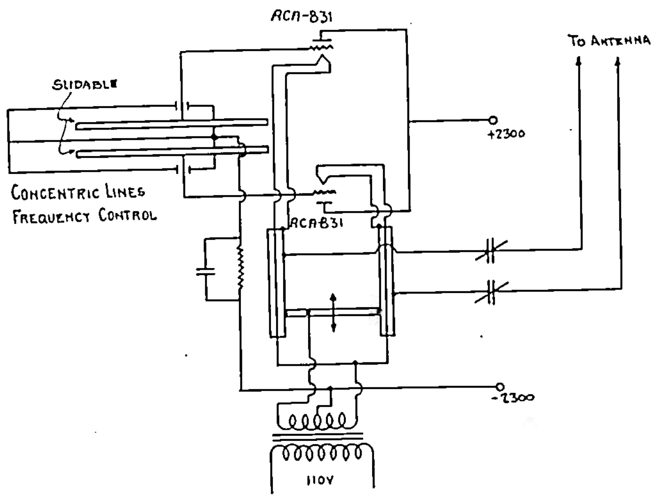

Fig. 2—Circuit of transmitter when operating at one hundred megacycles.

The transmitter consisted of a push-pull oscillator using RCA-831 tubes. No modulating means were provided. The circuit diagram of the transmitter for one-hundred-megacycle operation is shown in Fig. 2. A pair of open-ended concentric lines in the grid circuit were used for frequency stability. At one hundred megacyles the tube plates were closely bridged and the radio-frequency energy taken from the tuned filament circuit. At thirty megacycles the more conventional arrangement of tuned-grid—tuned-plate circuit was used.

The field strength was measured with a special battery operated superheterodyne receiver having a tuning range of thirty to one hundred megacycles, operated on a calibrated antenna. The circuit of the receiver is shown in Fig. 3.

A three-gang capacitor tuned the two radio-frequency circuits and the oscillator. The circuits were coupled so that the incoming signal and the oscillator voltage were both impressed on the grid of the first

through the standoff insulators, by means of the rope and pulley; this line could be raised and lowered to expose more or less of the top of the pole for radiation, for adjusting to the operating frequency.

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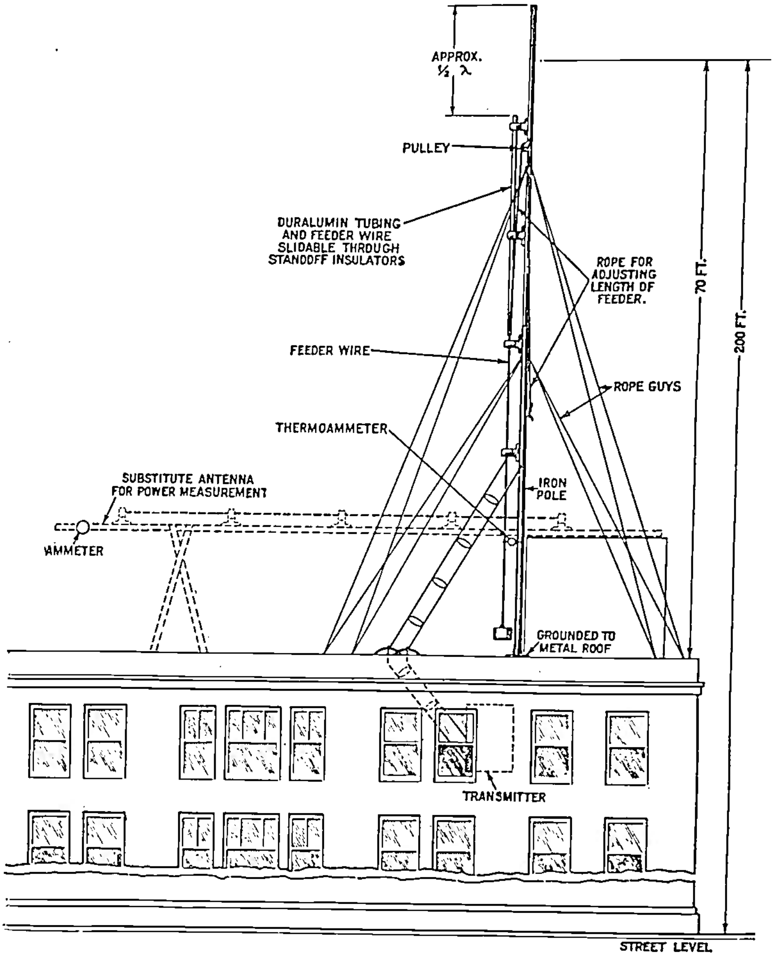

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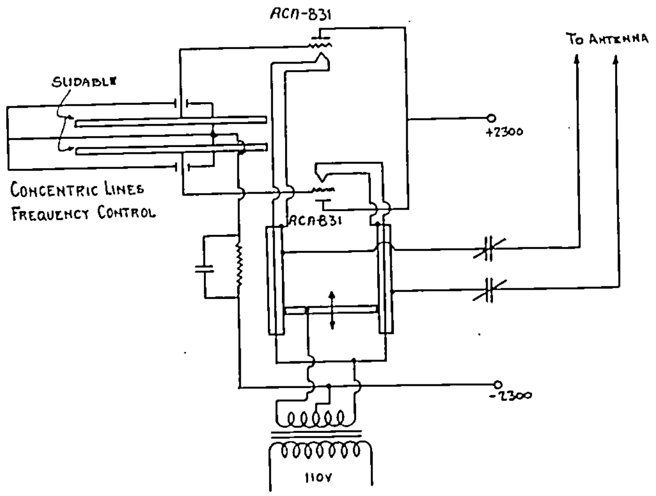


Fig. 2—Circuit of transmitter when operating at one hundred megacycles.

The transmitter consisted of a push-pull oscillator using RCA-831 tubes. No modulating means were provided. The circuit diagram of the transmitter for one-hundred-megacycle operation is shown in Fig. 2. A pair of open-ended concentric lines in the grid circuit were used for frequency stability. At one hundred megacyles the tube plates were closely bridged and the radio-frequency energy taken from the tuned filament circuit. At thirty megacycles the more conventional arrangement of tuned-grid—tuned-plate circuit was used.

The field strength was measured with a special battery operated superheterodyne receiver having a tuning range of thirty to one hundred megacycles, operated on a calibrated antenna. The circuit of the receiver is shown in Fig. 3.

A three-gang capacitor tuned the two radio-frequency circuits and the oscillator. The circuits were coupled so that the incoming signal and the oscillator voltage were both impressed on the grid of the first

through the standoff insulators, by means of the rope and pulley; this line could be raised and lowered to expose more or less of the top of the pole for radiation, for adjusting to the operating frequency.

In order to measure the antenna current, for computing the radiated power, a substitute antenna, located as shown in Fig. 1, was used. The horizontal substitute antenna was far enough from the roof so that

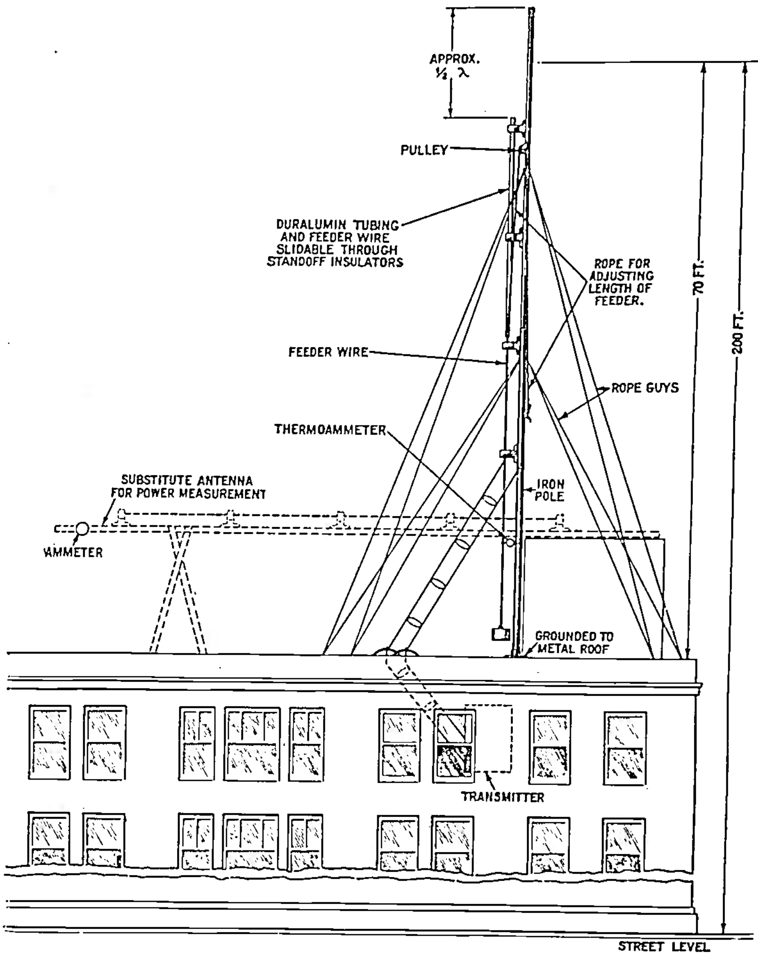
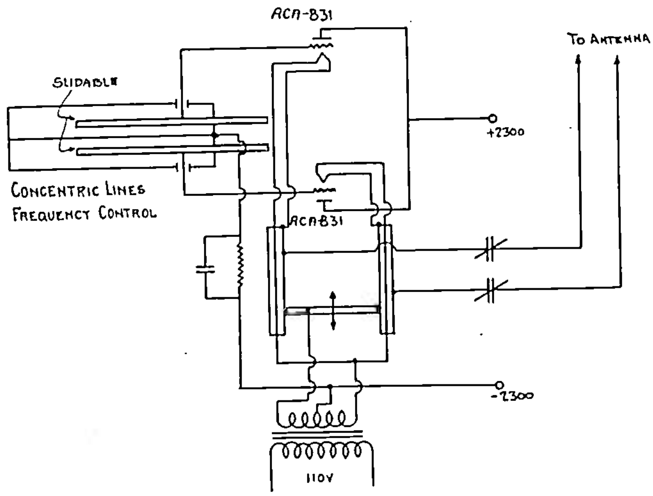


Fig. 1—Transmitting antenna arrangement.

the radiation resistance was not materially different from that of the vertical antenna. The current in the center of the vertical antenna was assumed to be the same as that in the substitute antenna when the feeder current was the same. The feeder current was maintained constant during all measurements at each frequency.

A further check of the radiated power was made by measuring the field intensity on the roof of a near-by brick tower at approximately the same elevation as the radiating portion of the vertical antenna. The

distance between the transmitter and the receiver was only slightly more than twice the elevation of each above the ground, and was partly occupied by several buildings having lower roof elevations. Under these conditions reflection was probably negligible, and was neglected in the calculation of radiated power from these field intensity measurements. The receiver indicated twenty per cent more field intensity at one hundred megacycles, and two per cent more at thirty megacycles, than should be produced by the current measured in the horizontal antenna and assumed to be the same in the vertical antenna. The radiated power is assumed to be that calculated from the antenna current, and all the data in this paper have been adjusted to one kilowatt radiated power.



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A three-gang capacitor tuned the two radio-frequency circuits and the oscillator. The circuits were coupled so that the incoming signal and the oscillator voltage were both impressed on the grid of the first

detector. From the detector the intermediate-frequency signal passed through the three-stage intermediate amplifier to the grid-leak detector and the audio amplifier. A gain control operated on the bias of the three intermediate amplifier tubes. The attenuation characteristic of this control was determined at intermediate frequency. A microammeter in the plate circuit of the grid-leak detector indicated the change in plate current due to the signal, and its sensitivity was sufficient to indicate small changes in signal strength, since the steady component of plate current was balanced out of the meter by the bucking battery current.

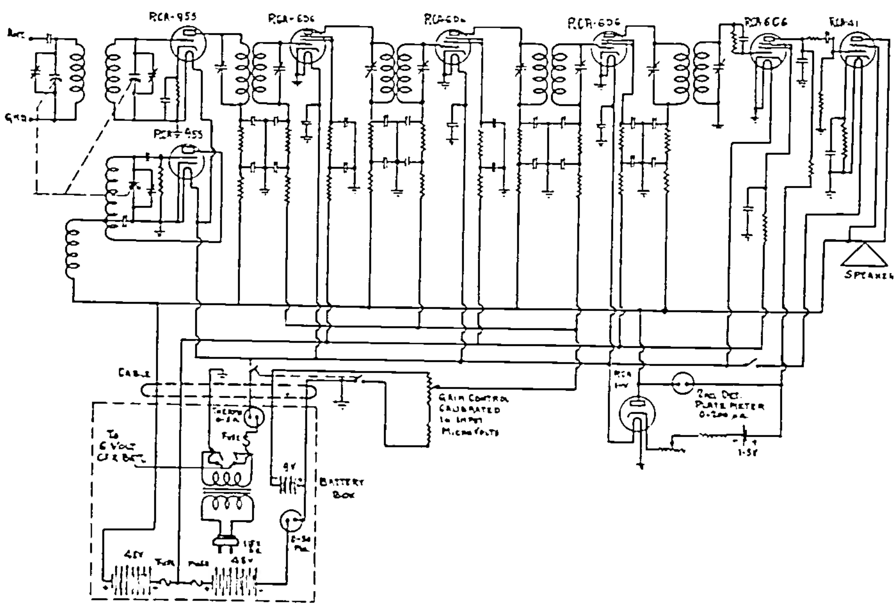

Fig. 3—Circuit of field strength measuring receiver.

The receiver was mounted in an automobile and connected to an antenna permanently mounted on the side of the car. The complete equipment was calibrated by subjecting it to a known field from a small transmitter, recording gain control dial settings for a given change in detector plate current against field strength in microvolts per meter for several different field strengths. The curve thus obtained was then extended to the limits of sensitivity of the receiver by applying the attenuation characteristic of the gain control, previously obtained. A separate calibration was made at each of the two frequencies, and rechecks were made at frequent intervals during the survey.

The survey was made by driving the car along roads fairly well distributed over the area within fifteen miles of the transmitter, and measuring the field strength at frequent intervals. It was found that a con-

inuous check of the field strength could be made when the car was lriven along at a slow rate of speed; whenever the average reading hanged materially it was recorded. The points were identified on the nap by their distance from known landmarks, such as main interections, etc. The standing wave pattern was very pronounced, paricularly at one hundred megacycles, causing wide apparent variations n field strength even in very short distances, but by driving the car

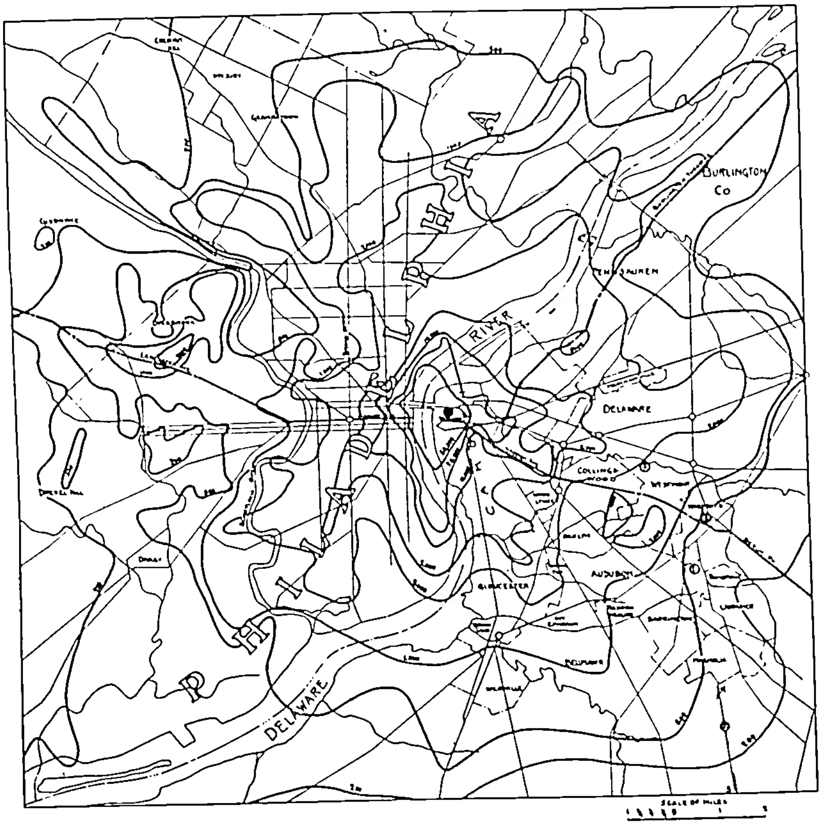

Fig. 4—Thirty-megacycle contour map. Contours of equal field intensities in microvolts per meter.

at a constant rate of about fifteen miles per hour it was found that these variations could be readily averaged out, so all the recorded readings were average field strength, usually averaged over a distance of about one to two hundred feet. At each frequency about 2000 readings were taken.

In addition to the measurements made for the purpose of drawing the contour maps, measurements were made along three routes radiating more or less directly from the transmitter. These routes were chosen as being widely different in ground profile characteristics; one was fairly level ground, one gently rising, and the other rising more rapidly.

The elevation data for these routes were obtained from The United States Geodetic Survey Maps (1898).

In order better to tie the results of the survey to actual operating conditions for receivers in fixed locations, signal measurements were made at three representative residences. Measurements of actual input to the antenna post of the receiver with several different types of antenna at several locations in the house were made.

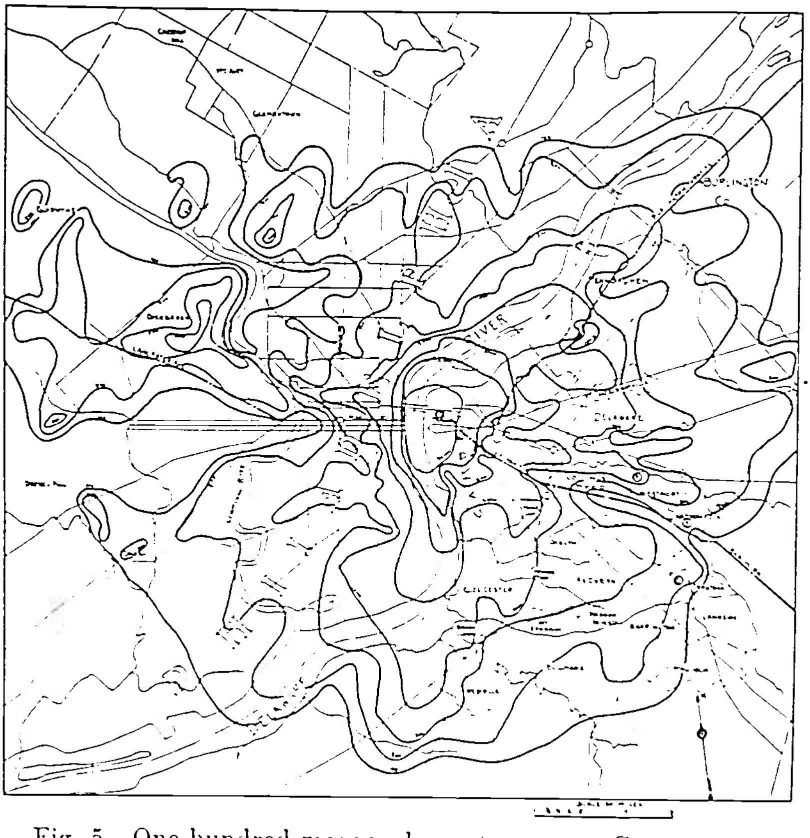

Fig. 5—One-hundred-megacycle contour map. Contours of equal field intensities in microvolts per meter.

Results of the Survey

Most of the measurements in this survey were made for the purpose of obtaining the field strength contours within a radius of ten to fifteen miles from the transmitter. The points taken at each frequency were plotted on large scale maps and the contour lines for equal field strength were drawn. Fig. 4 is the map for thirty megacycles, and Fig. 5 for one hundred megacycles.

In order to obtain more generalized results from these data, the area enclosed by each contour was measured and the average[2] radius

[2] The radius was determined from the relation $r = \sqrt{A/\pi}$, where A is the area of the contour. The r, of course, is the radius of a circle having this same area,

determined. The average radii were used as the basis for plotting the curves in Figs. 6 and 7 showing the average signal at the two frequencies as a function of distance from the transmitter. No effort has been made to determine the exact law governing the rate of attenuation. At distances between one and ten miles the curves are nearly straight

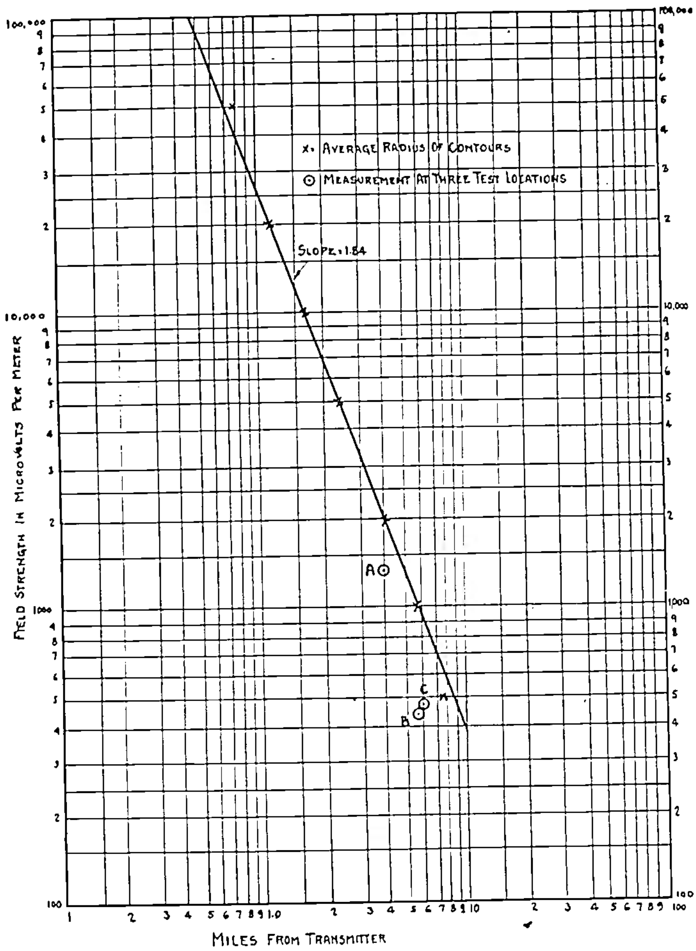

Fig. 6—Thirty-megacycle survey average.

on logarithmic paper, and have slopes of approximately 1.84 at thirty megacycles and 2.5 at one hundred megacyles. At distances less than one mile, the attenuation is probably more nearly directly proportional to distance, as indicated by some points that were taken but not plotted on the maps or curves, and beyond ten miles the curves probably have a greater slope.

which is the effective radius of the contour. The greater the deviation of the shape of the contours from circles, the greater the deviation of the effective radius as determined by the above relation from the true average radius. The contours under consideration are near enough to circles so that the error in calling effective radius average radius is small, and for simplicity this has been done in this paper.

Several interesting observations were made during the course of these measurements. The standing wave patterns were, in general, more severe in built-up sections than in the open country. When traveling on north and south streets in downtown Philadelphia the field strength usually increased very greatly when passing an intersection where the signal could come directly up the street from the transmit-

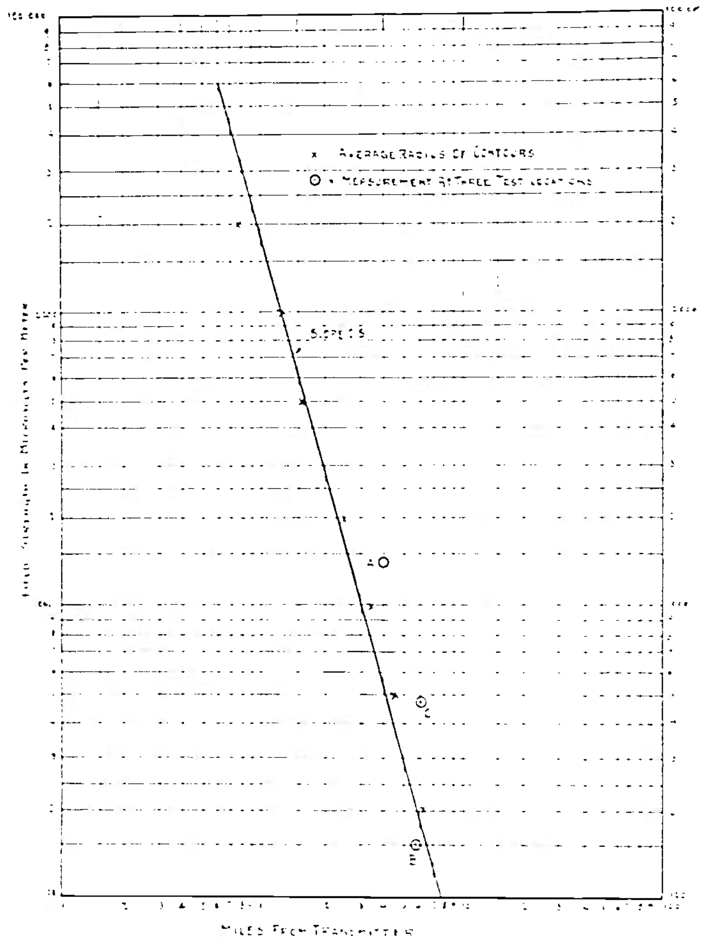

Fig. 7—One-hundred-megacycle survey average.

ter, instead of having to go through and around buildings. The shielding effect of the thickly built-up downtown area of Philadelphia is very apparent on the contour maps, particularly at one hundred megacycles where the signal practically disappears behind the buildings. The signal was attenuated less up and down the Delaware River because of the fewer buildings and other obstructions in these directions. The greatest field strength was usually obtained on the brows of hills facing the transmitter; beyond the brow of a hill the field strength usually de-

creased, even though the elevation might continue to increase gradually.

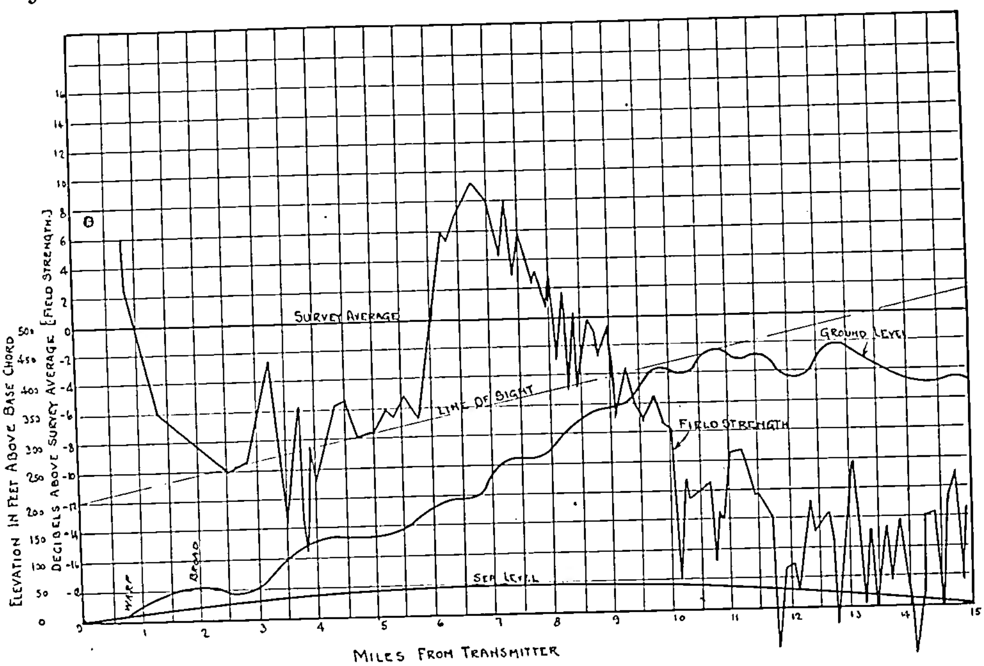

Fig. 8—Thirty-megacycle profile—Lancaster Ave.

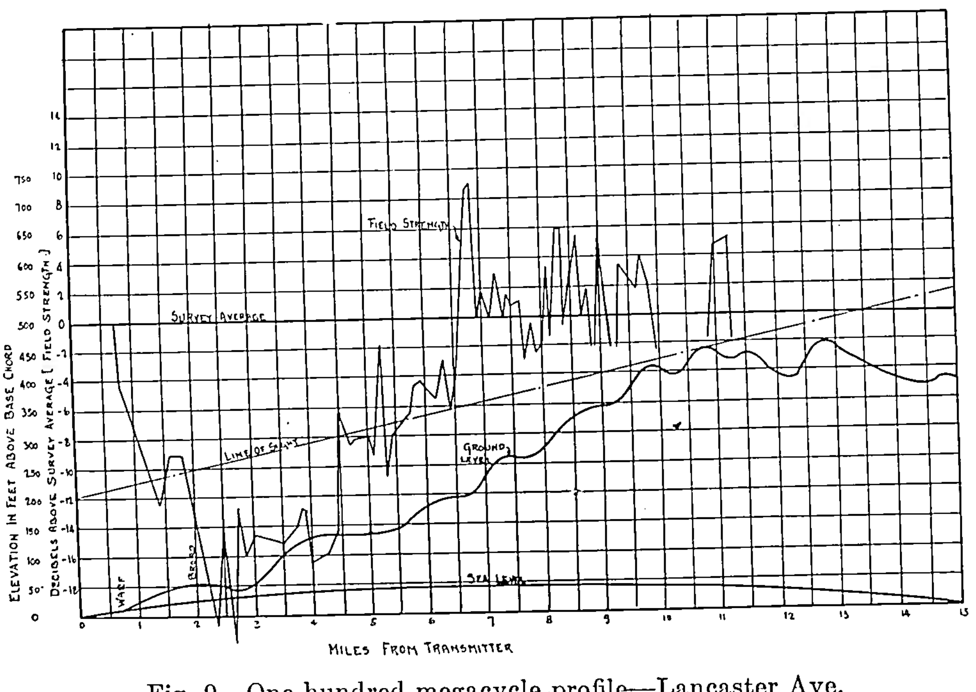

Fig. 9—One-hundred-megacycle profile—Lancaster Ave.

In order to determine the relation of the ground profile to the field strength, three routes radiating more or less directly from the trans-

mitter were selected and additional measurements made along them. These routes are shown in dot-dash lines on the contour maps. One

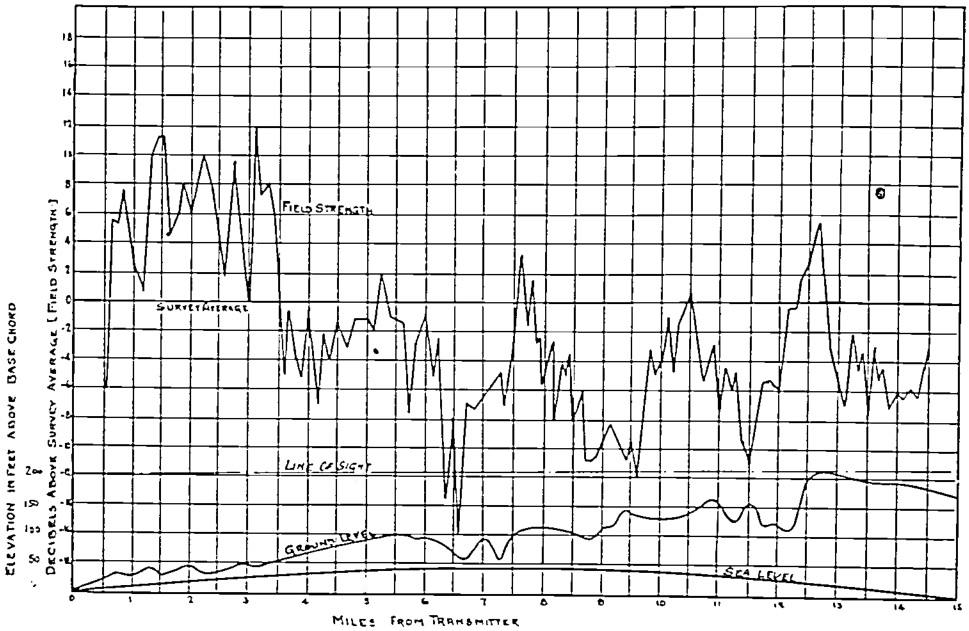

Fig. 10—Thirty-megacycle profile—Berlin Road.

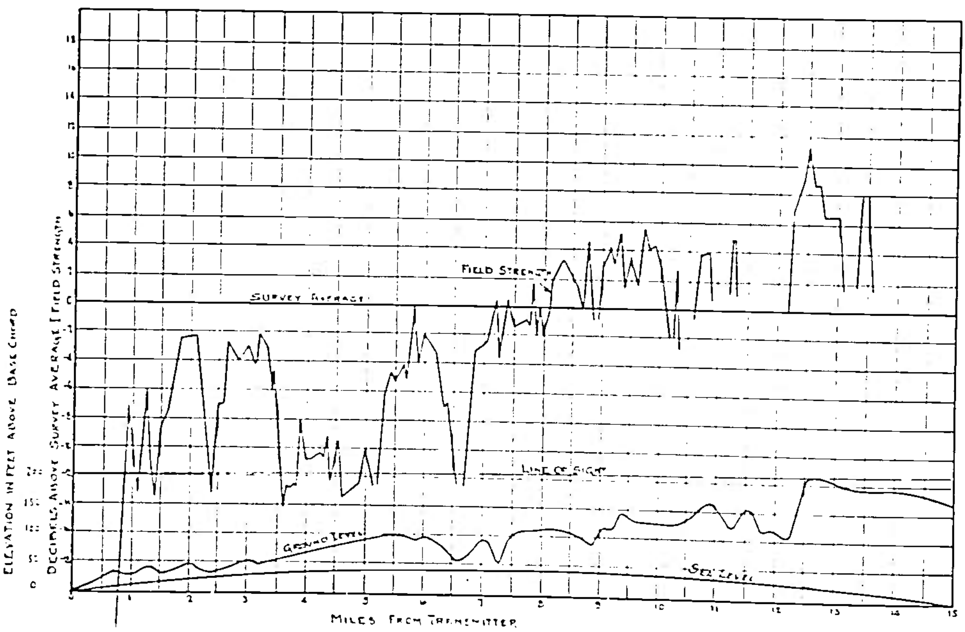

Fig. 11—One-hundred megacycle profile—Berlin Road.

route was through Philadelphia on Market Street and out Lancaster Avenue. This route was chosen because of the hills it passed over on

the far side of Philadelphia. Readings were taken very close together along this route, and plotted as variation from the survey average, in

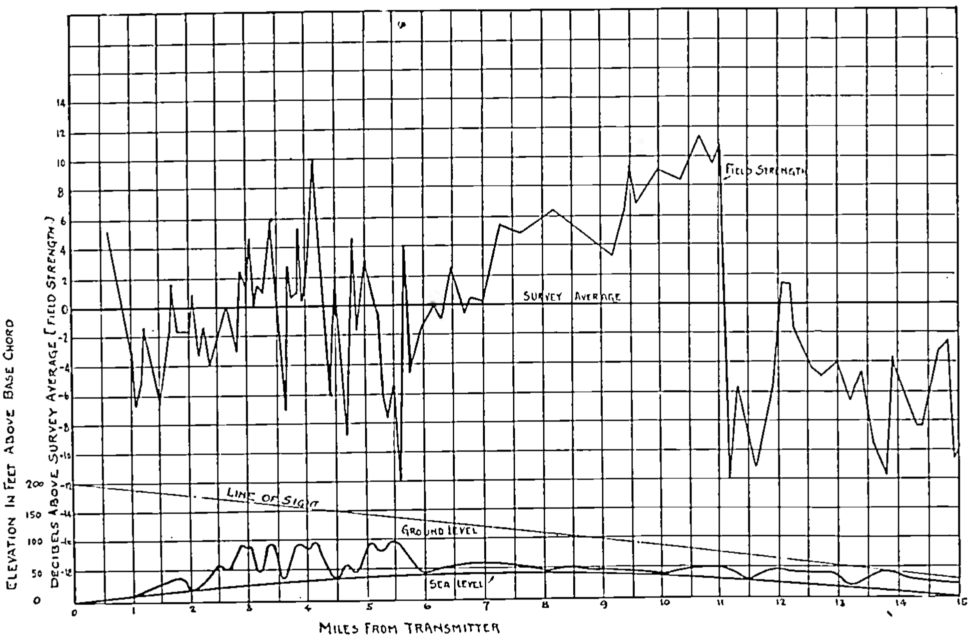

Fig. 12—Thirty-megacycle profile—Burlington Turnpike.

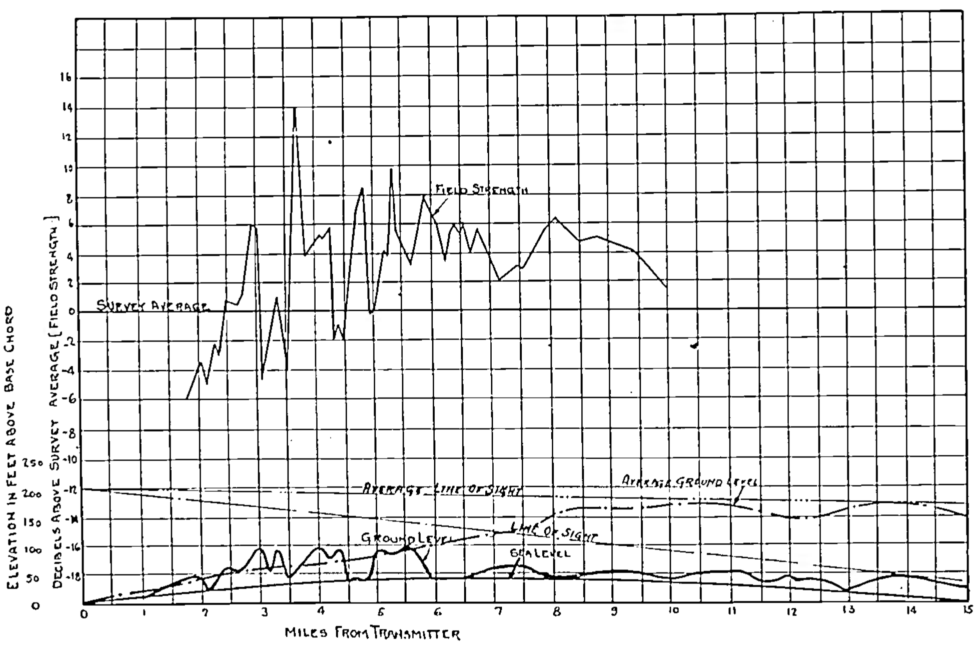

Fig. 13—One-hundred-megacycle profile—Burlington Turnpike and average profile around transmitter.

decibels, at the various distances from the transmitter. Figs. 8 and 9 are the curves obtained over this route at thirty and one hundred meg-

acycles, respectively. In the same figures are plotted the ground elevation above a fifteen-mile chord. Some correspondence between the elevation and the field strength can be seen on these curves, most notably the high field strength at the brows of hills, but it shows that local conditions have a very large effect and at times completely mask the relation between elevation and field strength.

The second route selected was almost directly opposite the first, toward Berlin, New Jersey, and is most notable because of the steep hill about twelve and one-half miles from the transmitter. The curves for this route are shown in Figs. 10 and 11, and the increase in field strength at the brow of the hill is very noticeable at both thirty and one hundred megacycles.

The third route is along the Delaware River on the New Jersey side, out the Burlingron Turnpike. This route is the most level of the three, and the signal remains the most constant along this route, as shown by Figs. 12 and 13. There is less built-up area along this route than either of the others, and this is also a factor in the reduction of field strength variations.

Fig. 13 also shows the average elevation of the ground in all directions from the transmitter. It is included for comparison with the other curves, and was obtained by plotting the average elevation along sixteen radii from the transmitter. The average ground level rises more or less uniformly to a distance of about ten miles from the transmitter and then levels off. Line of sight extends out to about ten miles, and remains approximately parallel to the ground to about fifteen miles from the transmitter.

After the field strength contour map data had been obtained it seemed desirable to measure the signals actually obtained in some representative locations in order to relate better the field strength measurements with actual receiver performance that might be expected in a home installation. Measurements were made at three locations, two in Haddonfield and one in Collingswood, New Jersey, identified as A, B, and C on the maps. In each case the field strength was measured by driving the car along the street in front of the house, and into the driveway, and taking the average of the measurements thus obtained as the field strength outside the house. The receiver was then taken into the house and the actual microvolts on the antenna post measured for several different antennas in several different locations. Table I is a tabulation of the data thus obtained.

The short antenna referred to in Table I has the length nearest to a half wavelength with which the greatest signal was obtained on the antenna post of the receiver. For thirty megacycles this length was

twelve feet, and at one hundred megacycles, five feet. These lengths are not a half wavelength because of the effect of the receiver input circuit on antenna resonance, and bear a different ratio to a half wave length at the two frequencies because of the different characteristics of the receiver input circuit at the two frequencies.

The zeppelin antenna was the same at each location; a half wavelength vertical wire hung on the highest convenient point on the roof of the house, usually the pole supporting the broadcast antenna, with a fifty-foot transmission line leading down to the receiver in the living

TABLE I

LOCATION A: A superior location, line of sight, four miles from transmitter, elevation 35 feet.

	30 mc	100 mc
Field strength outside of house	1330 μv/m	1440 μv/m
Receiver Location		
1st floor (living room)		
Short indoor antenna*	3400 μv	770 μv
Broadcast antenna	1570	264
Zeppelin antenna to roof	8300	1920
3rd floor (attic)		
Short indoor antenna	10800	1920

LOCATION B: An inferior location below line of sight, 5¾ miles from transmitter, elevation 50 feet.

	30 mc	100 mc
Field strength outside of house	450 μv/m	150 μv/m
Receiver Location		
1st floor (living room)		
Short indoor antenna	1400 μv	100 μv
Broadcast antenna	1080	105
Zeppelin antenna to roof	600	180
2nd floor (attic)		
Short indoor antenna	3000	—

LOCATION C: A superior location, line of sight, six miles from transmitter, elevation 110 feet.

	30 mc	100 mc
Field strength outside of house	480 μv/m	480 μv/m
Receiver Location		
1st floor (living room)		
Short indoor antenna	1800 μv	240 μv
Broadcast antenna	1080	550
Zeppelin antenna to roof	3000	1320
2nd floor (den)		
Short indoor antenna	2250	640
3rd floor (attic)		
Short indoor antenna	5650	1200

* A wire twelve feet long for thirty megacycles; five feet long for one hundred megacycles.

room. The broadcast antenna was in each case the one used with a broadcast receiver and in no case was it an all-wave antenna or one designed for short-wave reception. No tuning was added to the antenna to increase the signal obtained. Where the measurements were made in rooms other than the attic, the receiver was placed in the position most suitable for the permanent installation of a radio receiver in that room, and it was not moved about in the room to find the location where the strongest signal was obtained.

The three locations are all approximately in the same direction from the transmitter. An examination of the thirty-megacycle contour map shows a general indentation in the contours in this direction, in-

dicating that the general level of field strength was lower than in most other directions. Locations A and C were considered superior locations, but due to the general low signal the field strength measurements at these locations, plotted on Fig. 6, were below the survey average. Location B was considered an inferior location because it was below line of sight, and the field strength there fell further below the average. At one hundred megacycles the contours do not show the general indentation in this direction, and the field strength measurements at locations A and C lie above the survey average when plotted on Fig. 7, while that at location B is below, as would be expected. The difference between superior and inferior locations is much greater at one hundred megacycles than at thirty megacycles.

An interesting comparison of the effectiveness of transmission at thirty megacycles with that at one hundred megacycles under practical operating conditions can be made by applying the data given in Table I. The ratio (R) between the signal (in microvolts) on the antenna post of the receiver inside the house and the field strength (in microvolts per meter) outside the house was computed for the condition of the short indoor antenna, with the receiver on the ground floor. The average ratio at thirty megacyles is 3.2 and at one hundred megacycles it is 0.6. This ratio includes the effect of attentuation through the walls, reflections from the metal parts of the house, etc., as well as the effective height of the antenna.

Absorption and reflections are a function of the building construction and are very erratic, so the ratio R would be expected to vary widely between different buildings and between different locations in the same building—the values of R derived from the measurements tabulated in Table I are therefore only an indication of what might be expected in locations similar to those in which the measurements were made.

The factor of effective height of the antenna, which is also included in the general ratio R, is less dependent upon the location, and is primarily a function of the physical length of the antenna. The ratio of antenna lengths at thirty and one hundred megacycles is 12 to 5 or 2.4. This makes up a large portion of the difference in the ratios R obtained at the two frequencies, which is the ratio of 3.2 to 0.6 or 5.4.

Using the ratios (R) derived in this manner and the curves of Figs. 6 and 7, the average transmitter power required to deliver one hundred microvolts to the antenna post of a receiver operated under the above conditions at various distances from the transmitter was computed. The results of these computations are plotted in Fig. 14. These curves give a practical indication of the increase in power required for a given

service at one hundred megacycles over that required at thirty megacycles, taking into account the difference in the transmission characteristics of the two frequencies and also the effectiveness of the half wave length antennas, wall attenuations, etc., at the two frequencies. Points were also plotted on Fig. 14 showing the transmitter power required to deliver the one-hundred-microvolt signal to the receiver in

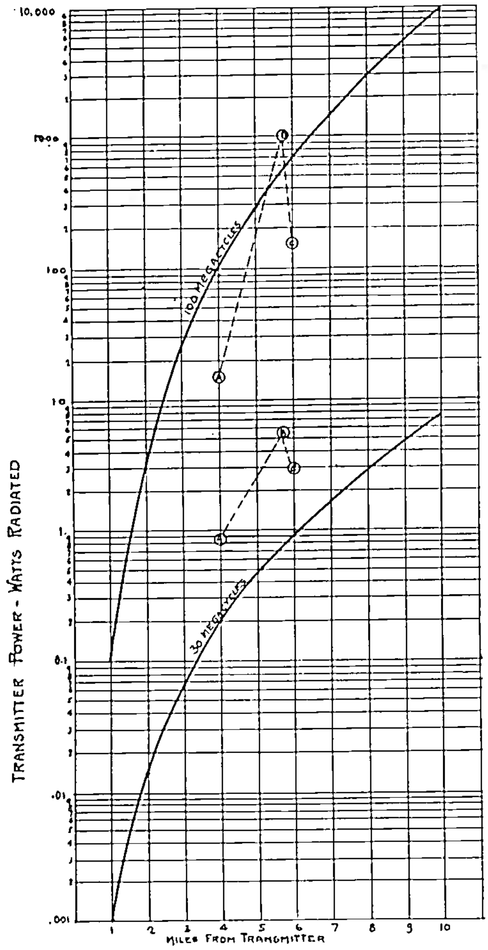

Fig. 14—Transmitter power required to deliver one hundred microvolts to the input of the receiver when using a short indoor antenna on the ground floor of a house at the indicated distance from the transmitter. Points *A*, *B*, *C* are for the three test locations of Table I. Antenna length for one hundred megacycles, five feet; for thirty megacycles, twelve feet.

the houses at locations *A*, *B*, and *C*, where measurements were actually made. The results presented apply only to the particular conditions under which the survey was made, and would be materially modified for other conditions. In particular, the transmitter location and the character of the surrounding territory will be a large factor in determining the service range. For a more practical installation the transmitter

antenna might be elevated considerably above the 200 feet used for this survey. Increasing the transmitting antenna height would increase the service range, or, for a given service range, decrease the required transmitter power. It would also reduce somewhat the difference in power required at one hundred megacycles compared to that required at thirty megacycles, for a given coverage, since a greater portion of the transmission path would be through free space, where the attenuation at the two frequencies is nearly the same, and a smaller portion through and near obstacles which attenuate the higher frequency more than the lower frequency. These factors are recognized, but since the survey was made for only one transmitter antenna height, no data are presented to indicate their magnitude.

Acknowledgment

Mr. R. D. Kell and Mr. C. D. Kentner of the RCA Manufacturing Company, Inc., built and operated the transmitter used for this survey. Mr. H. C. Allen assisted in the work of making the field strength measurements.

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A NEW METHOD OF MODULATING THE MAGNETRON OSCILLATOR*

By

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Summary—*In the new technique of the ultra-short waves the magnetron oscillator plays an important rôle. The shortest wave lengths as well as the largest powers have been obtained by using magnetron oscillators. Its use for radio communication purposes was limited however by modulation difficulties.*

The method of modulating magnetron oscillators described here is based on the application of an additional electrode placed in the magnetron tube; the modulation occurs by varying the potential of this electrode. The first investigations of this method have dealt with the split-anode magnetron acting as the "dynatronic" oscillator (negative resistance type). Nevertheless further experiments are carried on with the modulation of the "electronic" oscillator.

The Modulation of Magnetron Oscillators

The amplitude of high-frequency current in the oscillating circuit of a magnetron I_{osc} depends on the emission current I_e, the anode voltage E_a, and the magnetic field strength H,

$$I_{osc} = f(I_e, E_a, H). \tag{1}$$

Thus the modulation of the oscillating current can be obtained by varying one of these factors.

In the ordinary magnetron tubes the modulation of the emission current with the help of the filament current variation cannot be used, because of the thermal inertia of the cathode. The magnetic field strength or the anode voltage modulation only can be used.

Fig. 1 represents a static characteristic of the anode modulation, obtained under ordinary conditions in the magnetron oscillator. It is known that this kind of modulation is not satisfactory; the oscillations start suddenly at a certain value of the anode potential, their amplitude remains constant in a certain range of voltage, and then falls rapidly to zero.

Though by means of special adjustments this curve can be improved, nevertheless it is rather difficult to keep these adjustments stable in practical operating conditions.

The unsatisfactory form of the static characteristic of anode modulation in the magnetron generator is due to the cutting action of the magnetic field; for a given anode potential E_a there is only a limited

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value of the magnetic field strength H where the oscillations occur. In the cylindrical tube this field strength is determined by the "critical field"

$$H_{cr} = \frac{6.72}{r_a}\sqrt{E_a} \tag{2}$$

where r_a is the anode radius. For constant field H the oscillations occur only in a small range of the anode potential E_a according to (2).

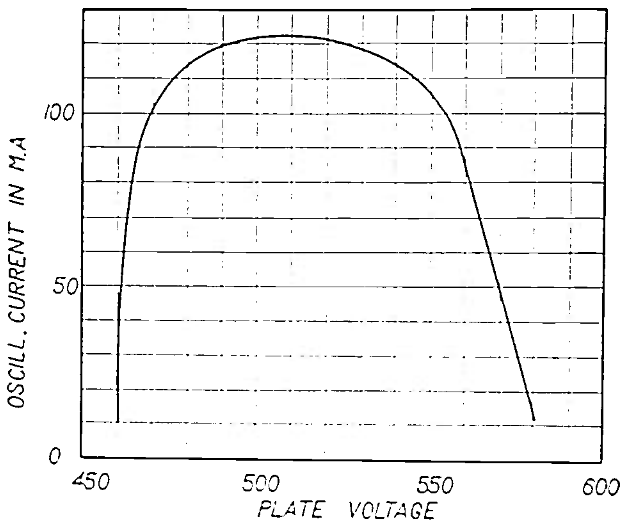

Fig. 1

Modulation by varying the magnetic field strength is unsatisfactory for the same reasons as the anode modulation: moreover this modulation presents difficulties in the practical utilization of the magnetron.

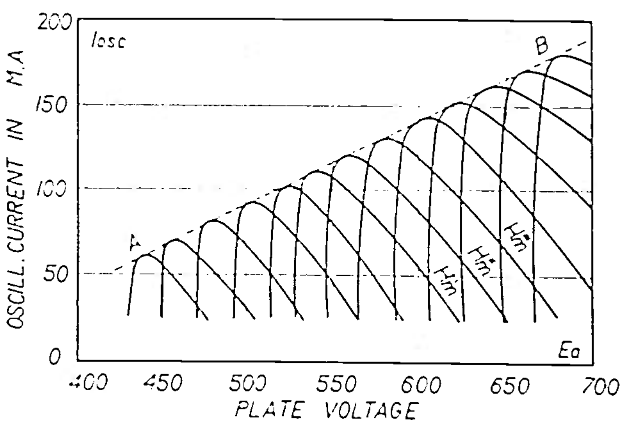

Fig. 2

Better modulation can be obtained by the simultaneous variations of the anode voltage E_a and the field strength H.

In Fig. 2 is shown a family of static characteristics of the anode modulation for the different field strengths.

From these curves we can deduce that the static characteristics of modulation by simultanous variation of E_a and H can be straight lines like AB in Fig. 2. Unfortunately, this method of modulation is complicated and rather useless for practical purposes.

Special Magnetron Tubes

From the above we see that the difficulties of the modulation of the magnetron oscillator are due to the interdependence which exists between the anode voltage and the magnetic field strength, given by (2).

The fact that (2) contains the anode radius has suggested to us the idea of the design of a tube with the anode of a special shape. It was supposed that by suitably choosing this shape, (2) would be fulfilled for a constant magnetic field at different anode voltages. The anode of the designed tube had the form of a cutoff cone. It can be considered as a series of parallel connected elementary tubes of different radii.

For a constant magnetic field and for varying anode voltages the high-frequency oscillations will be produced in the elementary tubes corresponding to the radii which fulfill (2). Therefore, by giving to the anode an adequate shape, it would be possible to obtain a uniform increase of the oscillating current with the rising of the anode voltage.

The experiments carried out with such a tube showed however that this reasoning is right only for a series of independent tubes connected in parallel. But the characteristics of the tube with the conic anode differ only slightly from these with a cylindrical anode. This is probably caused by the existence of the space charge, which changes the electric field in such a way that even at the lowest anode voltage, which corresponds to the oscillations occuring in the smallest anode radius, almost the total emission current reaches the anode and by this the oscillation energy remains constant in the whole range of the varying voltages.

The Grid Magnetron

The experiments described below show that it is possible to obtain a very good modulation by varying the potential of a supplementary electrode placed in the magnetron.

In the tube designed and made in the vacuum laboratory of the State Institute of Telecommunications this electrode had the form of a cylindrical spiral placed like a grid in an ordinary triode, between the

split anode and the cathode. This electrode will be called the grid, and the tube, the grid magnetron.

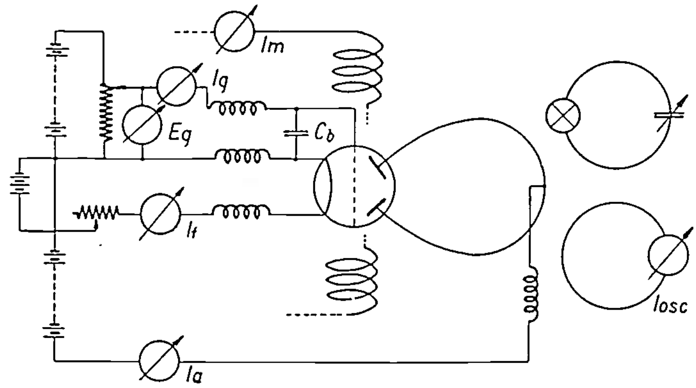

Fig. 3

The grid magnetron was examined in the circuit as shown in Fig. 3. Both split anodes were joined together by the help of a metallic loop which constituted, with the interelectrode capacity of the tube, the oscillating circuit. This circuit was coupled inductively with the thermoammeter circuit and with the dummy antenna circuit. The grid was shunted by a small condenser (150 micromicrofarads) to the cathode.

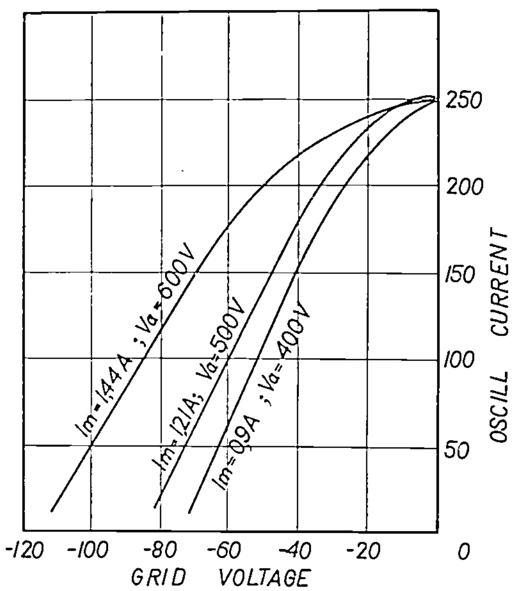

Fig. 4

The modulation characteristics $I_{osc}=f(E_g)$, i.e., the high-frequency oscillating current vs. direct-current grid-bias curve obtained by varying E_g at E_a and H constant, are shown in Fig. 4 for some values of

anode voltages and magnetic field. These characteristics prove that a deep and distortionless modulation is possible. Fig. 5 shows the characteristics for the same anode voltage but for various magnetic fields. It is seen that in this tube the influence of the magnetic field on the grid modulation characteristics is considerably smaller than in an ordinary magnetron for anode modulation. That is the advantage of grid modulation, because the maintenance of the constant supply voltages is here not so critical as in an ordinary magnetron.

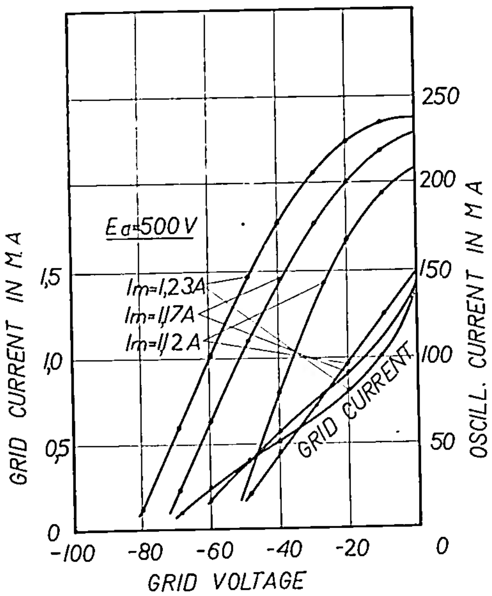

Fig. 5

In the same figure are given the curves, grid current I_g vs. grid potential E_g. As these curves in the modulation range can be considered as straight lines, the grid resistance at the modulation frequency is constant and has the value of about fifty kilohms; the modulation power is therefore rather small. The above curves have been obtained for the wavelength of about 180 centimeters. The wave length variations during the modulation have not been observed. The high-frequency output was determined by the help of the absorbing circuit with a incandescent lamp checked by direct current. For the maximum value of the high-frequency current in Fig. 5 this value was of the order of two watts. It corresponds to an efficiency of about twenty per cent.

This kind of grid magnetron modulation can be considered as the modulation by the variation of the total emission current in an ordinary magnetron. It results from the curves shown in Fig. 6 which give the dependence of the anode current, I_a, as the function of the grid voltage,

E_g. (These curves were obtained simultaneously with those shown in Fig. 5.) By varying the grid voltage, E_g, we control the number of

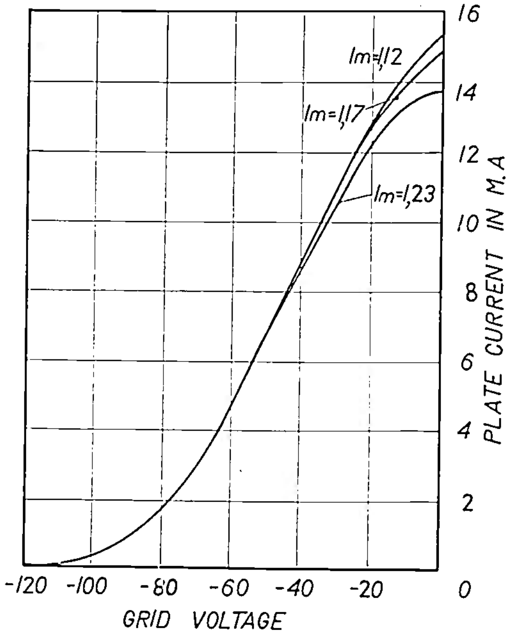

Fig. 6

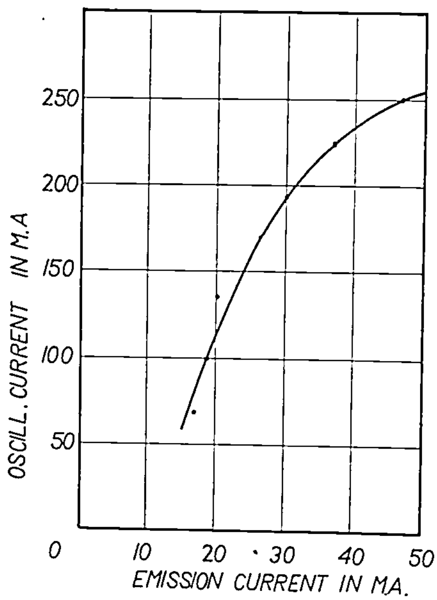

Fig. 7

electrons which take part in the production of oscillations. This reasoning is proved by the curve, oscillating current I_{osc} vs. total emission current, I_e, given in Fig. 7. This curve has been obtained for a grid

magnetron, the grid potential being zero, by varying the filament current, I_f. Its shape is analogous to the shape of the curves in Figs. 4 and 5.

Acknowledgment

The authors take pleasure in expressing their appreciation to Mr. Z. Jelonek for some of the discussions and to Mr. W. Górka for the construction of the tubes.

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EFFECTIVE RESISTANCE OF CLOSED ANTENNAS*

By

V. I. Bashenoff and N. A. Mjasoedoff
(Central Aero-Hydrodynamical Institute in the name of Professor Joukowsky, Moscow, U. S. S. R.)

Summary—This paper discusses the most desirable dimensions for closed antennas. The total resistance of the antenna is broken down into its several components. It is shown that the greatest losses are the dielectric losses in the earth and near-by objects, and formulas are given for calculating this component. Means are discussed for reducing the dielectric losses.

I. Introduction

THE resistance of a closed antenna is one of its fundamental parameters. As there are no formulas for determining this resistance, calculation of the constants of radio beacon transmitting antennas is not precise. Up to the present time, the problem of resistance of closed aerials is not quite clear and the limited available printed material does not permit making an estimate even of the ranges of resistance.

Starting with the experimental data obtained in co-operation with other persons, we shall consider in this section the problem of the structure of resistance of closed antennas and by using a number of practical considerations we shall make some indications as to the selection of the fundamental dimensions of antennas.

As we have shown previously,[1] the effective height of a closed antenna is largely dependent on the value of $k=\lambda/P$, λ being the working wave length and P the perimeter of the antenna. For large values of k, the effective height of a closed antenna is small, due to the smallness of the distances between opposite situated elements of the antenna perimeter in comparison with the wave length. Each pair of elements, carrying currents 180 degrees displaced in phase, is only weakly radiating. For small values of k, ($k \leqq 2$), the current distribution along the perimeter of the closed antenna is such that in both halves of the

* Decimal classification: R125.3. Original manuscript received by the Institute, July 11, 1935; revised manuscript received by the Institute, November 18, 1935. This is the third and last paper on the subject of the calculation of closed aerials. The first, by V. I. Bashenoff, "An abbreviated method for calculating the inductance of irregular plane polygons of round wire," appeared in the Proc. I.R.E., vol. 15, pp. 1013–1039; December, (1927), with a supplementary note, Proc. I.R.E., vol. 16, pp. 1553–1558; November, (1928). The second, by V. I. Bashenoff and N. A. Mjasoedoff, "The effective height of closed aerials," appeared in the Proc. I.R.E., vol. 19, pp. 984–1018; June, (1931). This paper is chapter V of the book "Radio Range Beacons" by V. I. Bashenoff and N. A. Mjasoedoff, published in Russian by Swjazteсnizdat, Moscow, 1936.

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antenna perimeter, symetrically disposed with respect to the vertical axis, currents of different elements have different directions. This is the reason why the antenna radiates mostly upwards. (In using radio beacons we are mainly interested in the waves traveling along the ground surface, and the waves reflected from the upper strata of the atmosphere may well be the cause of an unsteady operation of the beacon during the nighttime.) Therefore, for a given value of the active resistance, the estimation of the effectiveness of the closed antenna from its effective height should be calculated for the direction parallel to the ground surface.

Let us assume that the power of antenna is P_A, the active resistance of antenna is R_A, and its effective height is h_e.

Evidently the effective value of the current in the antenna is $I=\sqrt{P_A}/\sqrt{R_A}$ and the intensity of the field by the formula holding for ideal transmission is

$$E = \frac{120\pi I h_e}{\lambda d} = \frac{120\pi\sqrt{P_A}}{\lambda d}\cdot\frac{h_e}{\sqrt{R_A}} = C\cdot\frac{h_e}{\sqrt{R_A}} = C\cdot s \qquad (1)$$

where,

$$C = \frac{120\pi\sqrt{P_A}}{\lambda d} = \text{const, when } \lambda = \text{const}, d = \text{const, and } P_A = \text{const}$$

and,

$$s = \frac{h_e}{\sqrt{R_A}}. \qquad (2)$$

The value of s which equals in meter-amperes the moment of the antenna current in the direction of the maximum radiation when $P_A=$ one watt, might serve as a criterion of the effectiveness of the closed antenna under different values of h_e and R_A.

Experience and theory prove that, with increase of k, h_e, and R_A decrease simultaneously but that the decrease of h_e is the more rapid so that $s=h_e/\sqrt{R_A}$ decreases also. By decrease of k, s increases only up to a certain limit, since, when a certain value of $k=\lambda/P$ (near to $k=2$) is reached the effective height of the antenna begins to decrease while the active resistance of antenna continues to increase. As a result, we may expect the maximum of $s=h_e/\sqrt{R_A}$ with values of k which more or less approximate to 2, and one of the fundamental problems of this paper consists in defining the most useful range of values of k considered from the standpoint of giving sufficiently large values of s. In examining this problem, we shall take into account the following practical considerations. The heights of radio beacon masts

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do not usually exceed thirty-five meters (because of the inconvenience of having high masts near airdromes). At such heights it is not possible to design an antenna with a perimeter of more than 300 meters, since this would call for such great horizontal dimensions that it would create difficulties when suspending the network, and it would make the network either a cumbersome structure or mechanically unsteady (vibrations of wires due to the wind, etc.). Apart from this, excessive dimensions of antennas for beacons operating on closed antennas are unnecessary, since the range of these beacons at night is limited by the "night effect."

In consideration of the above, as well as the fact that beacons intended for long-distance guidance of airplanes usually do not operate on wavelengths shorter than 600 meters (leaving ultra-short-wave beacons out of account), we get for a minimum value of k,

$$k_{\min} = \frac{600}{300} = 2.$$

In favor of the selection of $k \cong 2$ there is the following further consideration: As it has already been shown,[1] the angle γ of the displacement of the current antinode in the case of electrical asymmetry of closed antenna is given by the formula

$$\operatorname{cotg} \gamma = \frac{C_1 + C_2}{C_1 - C_2} \operatorname{cotg} \frac{\pi}{k} + \frac{4C_0 k}{\pi(C_1 - C_2)}$$

where C_0 is the capacity of the closed antenna, and C_1 and C_2 are the capacities of the antenna terminals referred to ground. From this formula we find that the closed antenna is the more disposed to vertical effect (antinode current displacement greater) the smaller k is. The greater the value of $k = \lambda/P$, the freer (other things being equal) is a closed antenna from the vertical effect, and the greater is the safety of operation of the beacon.

Thus, when reviewing the problem of selecting the perimeter of a closed antenna we are limited by the condition

$$k \geqq 2. \tag{3}$$

The upper limit $k = \lambda/P$ will be defined, in agreement with experimental data, at a value of k for which $s = h_e/\sqrt{R_A}$ is beginning to decrease abruptly or at least is becoming substantially smaller in comparison with $S_{\max}$.

The conclusions and deductions relating to this problem are of no significance for marker beacons for blind landings as with such beacons

only short masts of six meters are usually used. The required range of action of this kind of beacon is not great (about 20 kilometers). Therefore, the perimeter of the antenna of a marker beacon must be considerably less than one which would be selected for use on a higher radio mast and $k \gg 2$ (for marker beacon antennas, $k \approx 10-15$). In view of the fact that the power of this type of beacon is known to be greater usually than that which is necessary for the required range of action, the problem of calculating the parameters of the antenna to determine the range of action of the beacon is not of such significance in the marker beacon case as it would have been in the case of a large antenna for a long range beacon.

II. The Effective and Apparent Values of the Active Resistance of Closed Antennas

Before proceeding to the investigation of the above-mentioned problems, we shall define more exactly what is meant by the active resistance of a closed antenna.

There is an evident relation connecting R_A, P_A, and I.

$$P_A = I^2 R_A, \qquad R_A = \frac{P_A}{I^2}. \tag{4}$$

Let us start with a purely formal treatment of this relation.

In the case of an antenna with an equal current distribution in (4) I might be supposed to be the current in any point of the perimeter of the closed antenna, since in all points of the antenna perimeter we have the same current and (4) has a definite meaning.

Under a current distribution which is not quasi-stationary, the value of $R_A = P/I^2$ is evidently dependent on the value of effective current which is assumed in this equation: whether it be the value of current in the antinode (I_{max}, Fig. 1), the value of current at the end (I_{min}) or some intermediate value of current (I). Thus, in the case of nonuniform distribution of current, the active resistance is the function of the co-ordinate of that point of the antenna perimeter where the current has the value to which the resistance is related. Therefore the conception of the active resistance of the antenna has a meaning only when there is specified at the start that point of the antenna perimeter where the current to which we have agreed to relate the resistance is supposed to be measured.

Limiting ourselves to the consideration of the cases where the antinode of current is in the upper middle point of antenna (point 0, Fig. 1) let us agree to refer the resistance of the closed antenna to the

current in this point; i.e., to the current in the antinode. This is convenient because of the following reasons:

(1) With given dimensions and power the current at the ends of a closed antenna is subject to casual changes in a greater degree than the current in the antinode. The small changes in the capacity of the wires which carry the current to the ends of the antenna, the humidity of the soil, etc., all affect the value of the current in the antinode to a lesser degree than the currents at the ends of antenna.

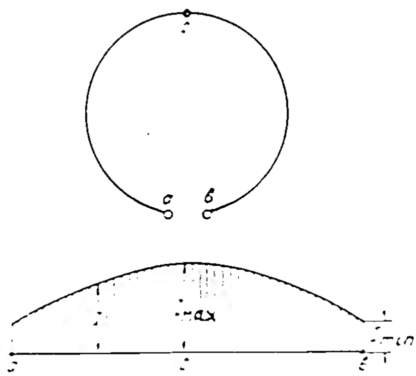

Fig. 1—Current distribution in a simple loop antenna.

(2) By referring the active resistance and the effective height (as was done earlier in this treatise) to the current in the antinode, we provide the possibility of a more exact calculation of the range of action of the antenna. Indeed, by changing the form of the closed antenna, the curve of the current distribution as a function of $k=\lambda/P$ does not maintain its form.

Nevertheless, when making calculations of effective height based on the current in the antinode, we may make use of the conception of a cosine current distribution ($I = I_0 \cos 2\pi x/\lambda$) as this cannot lead to great errors in calculations of the intensity of the antenna field. On the contrary, if we refer the effective height of the closed antenna to the current at its terminal points and apply this theoretical law of current distribution we should face the probability of gross errors.[1] As the ratio of the current in the antinode to the current at the end cannot be calculated with sufficient exactness according to theoretical formulas, then it would be best when referring the effective height to the current in the antinode to refer the active resistance to the same current also, thus avoiding the necessity of an inaccurate recount. The latter is a definition of resistance referred to the current in the antinode according to the certain value of resistance related to the current at the ends of

[1] *Loc. cit.*, Fig. 6, theoretical and actual curves of current distribution.

ntenna. By knowing the effective height (h_e) and active resistance of he antenna (R_A), both referred to the same current, we may define $=h_e/\sqrt{R_A}$ and then we may easily define the meter-ampere moment f the current of the radiant aerial (S) by

$$S = \sqrt{P_A \cdot s}. \tag{5}$$

Apart from these conclusions, which are based on practical considerations, on the one hand, and on purely formal considerations on the other, it is necessary to understand that the conception of active resistance, referred to the current in the antinode, corresponds in a greater degree than does any other treatment of the conception of active resistance of closed antennas to the real picture of phenomena that take place during the operation of the antenna. Fundamentally it is the more correct conception.

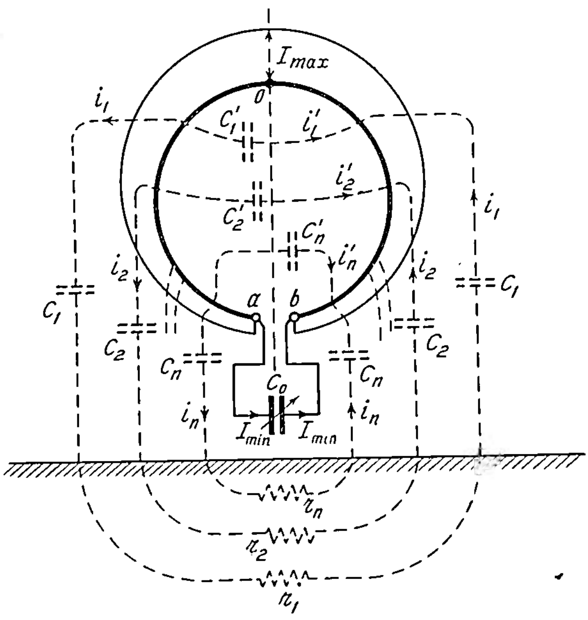

Fig. 2—Diagram showing the paths for capacity currents in the vicinity of a loop antenna located near the ground.

Let us assume (see Fig. 2) a closed antenna $a0b$, situated in the vicinity of the ground. The current I_{max} in the upper middle point of the antenna (point 0) is fixed partially by the capacity of C_0 (current I_{min}) of the condenser joined between the terminal points a and b of the antenna, and partially by elementary capacities

$$C_1,\ C_2,\ C_3,\ \cdots,\ C_n;\ C_1',\ C_2',\ \cdots,\ C_n'$$

$$(\text{currents } i_1,\ i_2,\ i_3,\ \cdots,\ i_n;\ i_1',\ i_2',\ \cdots\ i_n')$$

so that,

$$I_M = I_m + \sum_{n=\infty} (i + i'), \tag{6}$$

where $I_M = I_{\max}$ and $I_m = I_{\min}$.

The power of the antenna is composed of power losses in the resistance $r_1, r_2, \cdots, r_n$ and in the resistance of the antenna wire; power losses in eddy currents which are produced by the antenna in the earth and in surrounding objects; and losses from power radiated. The amount of these various power losses divided by I_M^2 is the active resistance of the antenna related to the current in the antinode.[2] Thus, by using the conception of the active resistance related to the current in the antinode, we take as a basis not only a purely formal application of (4), (which could have taken place, for example, in the case of referring active resistance and effective height to the current I_M as then the problem of the dimensions of the current I would be of no interest) but also by using the conception of active resistance related to the current I we proceed from the actual picture of currents in different elements and take into account all currents and powers.

Therefore, we shall term the active resistance of a closed antenna related to the current in the antinode its effective active resistance, R,

$$\frac{P_A}{I_M^2} = R. \tag{7}$$

Notwithstanding the principal merits and all the conveniences of using the conception of the effective active resistance as enumerated above, it happens that on some occasions it is possible to make an approximate judgment as to the power in an antenna by the current I_m at the terminal points a and b, as that current is more accessible to measurement.

By terming the resistance related to that current as *apparent* active resistance and denoting it by R_k, we have

$$R_k = \frac{P_A}{I_m^2} \tag{8}$$

and taking into consideration (7)

$$R_k = R\left(\frac{I_M}{I_m}\right)^2. \tag{9}$$

Assuming that the distribution of current follows the law

[2] The same as in "Principles of Radio Communication," p. 163, Morecroft, (1933).

$$I = I_M \cos \frac{2\pi x}{\lambda}$$

then,

$$I_m = I_M \cos \frac{2\pi \cdot P/2}{\lambda} = I_M \cos \frac{\pi}{\lambda/P} = I_M \cos \frac{\pi}{k}$$

and,

$$R_k = R \cdot \frac{1}{\cos^2 \pi/k}. \tag{10}$$

Actually[1] the ratio I_M/I_m is different from its theoretical value for different antennas in different degrees. Therefore, we shall accept

$$\frac{I_m}{I_M} = \psi(k) \tag{11}$$

where $k = \lambda/P$ and $\psi(k)$ is a function graphically represented in Fig. 3.

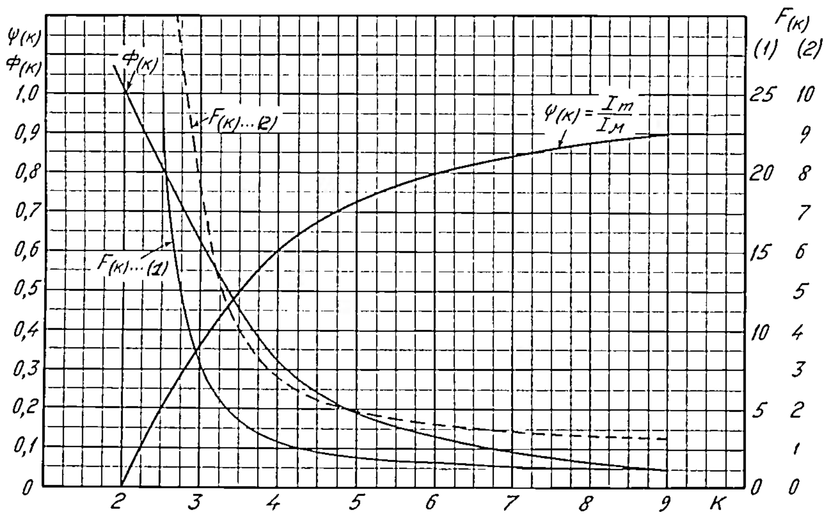

Fig. 3—Curves showing the variation of several functions vs. k, where k is the working wave length divided by the perimeter of the loop.

$$\psi(k) = \frac{I_m}{I_M} \qquad \phi(k) = k[1 - \psi(k)]^2$$

$$F(k) = \left[\frac{I_M}{I_m}\right]^2 = \left[\frac{1}{\psi(k)}\right]^2$$

This function has been obtained by working up the data of numerous experiments to obtain, for instance, the curve of average values I_m/I_M for closed antennas of different dimensions and configurations. It is understood that the result of calculations which is based on (11) cannot

[1] *Loc. cit.*, Fig. 7.

claim an absolute exactness. However, this result, in a great majority of cases, will be more nearly correct than calculations based on the purely theoretical formula (10).

Assuming that

$$\left(\frac{I_M}{I_m}\right)^2 = \left(\frac{1}{\psi(k)}\right)^2 = F(k) \tag{12}$$

we obtain

$$R_k = R \cdot F(k). \tag{13}$$

The function $F(k)$ is represented in Fig. 3.

Although, in the preceding exposition, the meaning of the term "apparent active resistance" is made sufficiently clear, still we shall explain it in an example. Suppose the antenna (represented in Figs. 1 and 2) works at its natural wave length, so that the current in the points a and b equals zero and the picture of current distribution is similar to what is represented in Fig. 4. Because $I_m=0$ we obtain $R_k=P_A/(I_m)^2=\infty$. In spite of this the power in an antenna and the current in the antinode do not equal zero! In this case, although the needles of the antenna ammeters are at zero, the antenna radiates, and in most cases, more intensively than at wave lengths greater than its natural wave lengths.

For the power in the antenna which is calculated from the current I_m and resistance R_k we obtain an expression of indefinite kind $P_A=(I_m^2)\cdot R_k=0\cdot\infty$ which indicates the artificiality of the conception of apparent active resistance, generally, and the absolute impossibility of using this conception in the case of waves which are close to the natural wave length of the antenna.

Lack of proper understanding of the effective and the apparent values of antenna resistance and radio loops was the reason for the erroneous deductions of some investigations[3] on the subject of the most profitable conditions of use of these antennas.

In order to make proper judgment from the current I_m of the radiation of a closed antenna, whose antinode of current is on the top, it is necessary to know the actual dependence of I_m/I_M on k that permits one to define the moment of the antenna current (h_cI_M) where h_c is effective height referred to the current in the antinode. Obtaining this dependence is possible only by means of experiment. It is necessary to realize, however, that when the waves are close to the natural wave length, any calculation of the moment of the current of a closed antenna will be sufficiently exact only if it is based on a direct measurement of the current in the antinode, as the natural wave length of the

[3] D'Armagnat, a French book, (1917).

antenna is not entirely invariable. To a certain degree it depends on the nature and conditions of the ground.

III. Components of the Effective Resistance of a Closed Antenna

Nomenclature.

P_A = full power of antenna

P_Ω = power losses in heating the antenna wires

P_L = power lost in eddy currents induced by the antenna in the ground

P_C = dielectric loss power; i.e., the power lost due to the passage of currents $(i_1, i_2, \cdots, i_n)$ in the ground

P_Σ = radiated power.

In accordance with Section II

$$P_A = P_\Omega + P_C + P_L + P_\Sigma = I_M{}^2 R,$$

hence,

$$R = \frac{P_\Omega}{I_M{}^2} + \frac{P_C}{I_M{}^2} + \frac{P_L}{I_M{}^2} + \frac{P_\Sigma}{I_M{}^2} = R_\Omega + R_C + R_L + R_\Sigma \cdots \quad (14)$$

where,

$R_\Omega = P_\Omega / I_M{}^2$ = resistance of wire antenna

$R_C = P_C / I_M{}^2$ = resistance equivalent of the dielectric losses

$R_L = P_L / I_M{}^2$ = resistance equivalent of the losses due to eddy currents induced by the antenna in the ground

$R_\Sigma = P_\Sigma / I_M{}^2$ = radiation resistance.

Let us examine each of the components of effective resistance of a closed antenna.

1. *Resistance of Antenna Wires* R_Ω.

The resistance might be calculated by formula

$$R_\Omega = P r_1 \cdot \alpha \cdot \beta \quad (15)$$

where,

P = perimeter of antenna

r_1 = direct-current resistance (one meter of antenna wire)

α = coefficient denoting how many times the wire resistance, for the given frequency, is greater than its resistance to direct current

β = coefficient accounting for the current distribution not being quasi-stationary.

Coefficient α in the first approximation might be calculated by the formula

$$\alpha = 0.05d\sqrt{\frac{f}{\rho}} \tag{16}$$

f = frequency in cycles
d = wire diameter centimeters
ρ = specific resistance in microhms/cm^3.

It is, however, necessary to bear in mind that calculations for the antenna depend in a great degree on the construction of the cable; that is, on the number of cores and the diameter of each core.

Coefficient β might be defined on the basis of the following considerations:

Let the resistance of a unit length of the antenna wire be $R_1 = R/P$. The power consumed in an elementary length of wire dx will be

$$dP = I^2 R_1 dx$$

or, assuming that the distribution of current is in conformity with the law

$$I = I_M \cos\frac{2\pi x}{\lambda}$$

$$dP = I_M{}^2 \cdot R_1 \cos^2\frac{2\pi x}{\lambda}\, dx.$$

Power consumed in heating all the antenna wires is

$$P = 2\int_0^{T/2} dP = I_M{}^2 \cdot R_1 \cdot P\left[\frac{1}{2}\left(1 + \frac{\sin 2\pi/k}{2\pi/k}\right)\right]$$

$$= I_M{}^2 \cdot R\left[\frac{1}{2}\left(1 + \frac{\sin 2\pi/k}{2\pi/k}\right)\right] \tag{17}$$

hence,

$$\beta = \left[\frac{1}{2}\left(1 + \frac{\sin 2\pi/k}{2\pi/k}\right)\right]$$

where $k = \lambda/p$.

The dependence of β on k for $k \geqq 2$ is represented graphically in Fig. 4.

2. *Resistance Equivalent to the Eddy-Current Losses.*

This resistance is known to be proportional to the square of the frequency

$$R_L = A\omega^2. \tag{18}$$

3. *Resistance Equivalent to the Dielectric Losses.*

Generally speaking, the dielectric losses are proportional to the wave length. In calculation of the dielectric loss in the earth for open antennas the formula of M. W. Schouleikin[4] $R_C = A\lambda/\lambda_0$ is largely used in the U.S.S.R. In this case it is necessary to take into consideration that these losses are the result of currents through the earth $i_1, i_2, \cdots, i_n$ (see Fig. 2). Thus other conditions being equal the dielectric losses increase nearly in proportion to that part of the maximum current (I_M) which flows through the external medium; i.e., in proportion to the relation of the current $I_M - I_m$ to the current I_M.

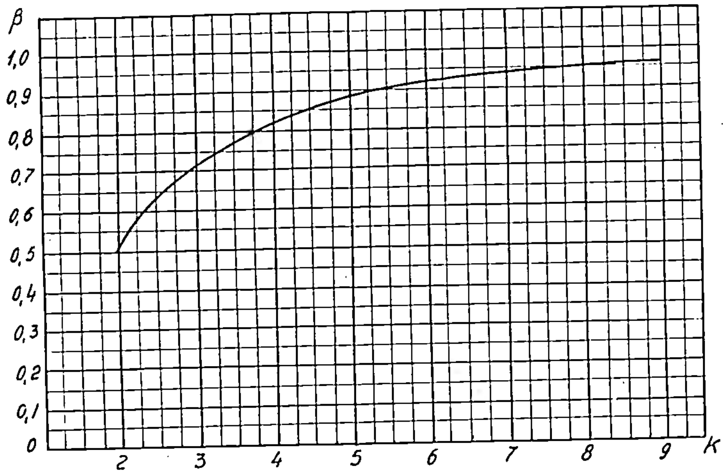

Fig. 4—Curve showing the dependence of β on k, where β is a coefficient used in (15) for taking into account the current distribution in a loop.

Proceeding from a cosine current distribution there is no difficulty in obtaining

$$\frac{I_M - I_m}{I_M} = \frac{I_M - I_M \cos \dfrac{2\pi \cdot P/2}{\lambda}}{I_M} = 1 - \cos\frac{\pi}{k}.$$

Power losses, and hence the resistance R_c, are proportional to the square of the current which produces these losses and consequently R_c is proportional to $(1 - \cos \pi/k)^2$.

Taking into consideration the proportionality of R_c also to λ/λ_0, which can be computed as proportional to $k = \lambda/P$ (because this ratio has a very low range of variation) we can write

$$R_C = B \cdot k\left[1 - \cos\frac{\pi}{k}\right]^2$$

[4] "Radiotechnik," (in Russian), No. 14, pp. 402–422; February, (1921).

where B is the proportionality factor or

$$R_C = B \cdot P \cdot \Phi_t(k) \tag{19}$$

where,

$$\Phi_t(k) = k\left(1 - \cos\frac{\pi}{k}\right)^2. \tag{19'}$$

As we have stated above, the curve $\psi(k)$, represented in Fig. 3, shows values of I_m/I which are closer to reality than the theoretical formula

$$\frac{I_m}{I_M} = \frac{I_M \cos\dfrac{2\pi \cdot P/2}{\lambda}}{I_M} = \cos\frac{\pi}{k}.$$

Therefore, we shall use the curve $\psi(k)$ in order to obtain the multiplier defining R_c. From $I_m/I_M = \psi(k)$ it is not difficult to obtain

$$\frac{I_M - I_m}{I_M} = 1 - \psi(k)$$

and then using arguments identical to those just stated

$$R_C = B \cdot k[1 - \psi(k)]^2 = B \cdot \Phi(k). \tag{20}$$

The function $\Phi(k)$ is represented in Fig. 3.

4. *Radiation Resistance.*

In most cases the radiation resistance of a closed antenna is very small in comparison with other components of R_A.

Assuming that the earth is an ideal conductor, we have for an antenna with uniform current distribution

$$R_\Sigma = 1600\,\frac{h_e^2}{\lambda^2} \tag{21}$$

$$h_e = \frac{2\pi s}{\lambda}.$$

For rough calculations this formula (21) might be used also in the case of nonuniform current distribution, assuming as a first approximation that the polar diagram of the radiated intensity of a closed antenna in its own plane is a circle and that generally the diagram of a closed antenna with nonuniform current is the same as in the case of uniform current distribution and ideally conducting earth.

IV. Examination of Experimental Data. Empirical Formula for the Calculation of the Resistance of Closed Antennas

Let us consider the experimental data. Curves 1 and 2 of Fig. 5, and curves 1 of Figs. 6, 7, and 8 represent the results obtained from experiments on the dependence of R on the wave length and on $k=\lambda/P$ for different closed antennas. (The data of these antennas are shown in the figures.)

Measurements of R were made by inserting a standard resistance into the antenna at the antinode (the top point of antenna) and measuring the current ratio resulting with the standard inserted and with

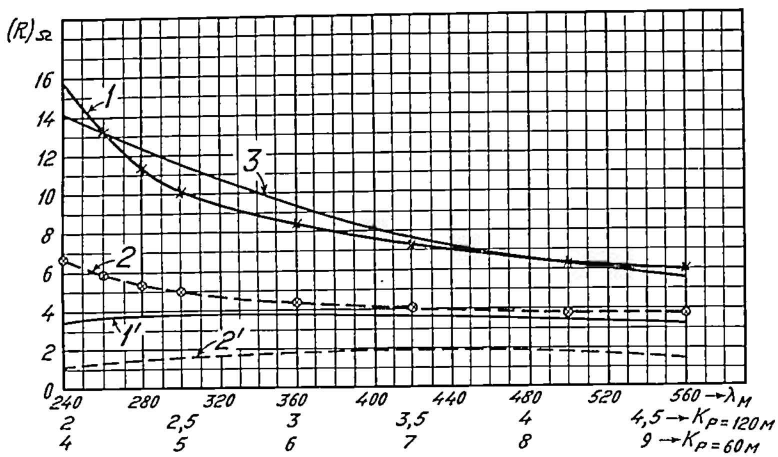

Fig. 5—Resistance at the center of a closed loop antenna vs. wavelength and the perimeter k_p of the loop.

Curve 1, measured values of total resistance of $k_p=120$ meters.
Curve 2, measured values of total resistance for $k_p=60$ meters.
Curve 3, calculated resistance for $k_p=120$ meters and $A=10$, including conductor and dielectric losses.
Curve 1′, calculated resistance of loop conductors only, for $k_p=120$ meters.
Curve 2′, calculated resistance of loop conductors only, for $k_p=60$ meters.

the standard short-circuited. There existed a very weak coupling between the antenna and a sufficiently powerful generator. If the above-mentioned ratio is α,

$$R = R_{st}\frac{\alpha}{1-\alpha}$$

where R_{st} is the resistance of the standard. As the currents in the antenna were so small that they were not directly measurable (voltage at the antenna terminals being of some volts) it became possible, on the one hand, to make a standard resistance out of very thin nichrome wires, thus providing the absence of capacity and inductance, and, on

the other hand, it was necessary to resort to indirect measurement of α. For this purpose a vacuum tube voltmeter was used for measuring the voltage at the terminals of a turn of wire placed on the ground at some distance from the antenna. There was no direct connection between the turn and the generator. The standards had different resisttances and each measurement was made twice with two standards of different resistances. The difference between the measured values did not exceed three per cent. As a rule, for each curve the measurement was taken twice. Tuning of the closed antenna was made with an adjustable condenser, the latter being inserted parallel to the antenna terminals. Measurements of R were made with $k=\lambda/P=2$ to 7. Al-

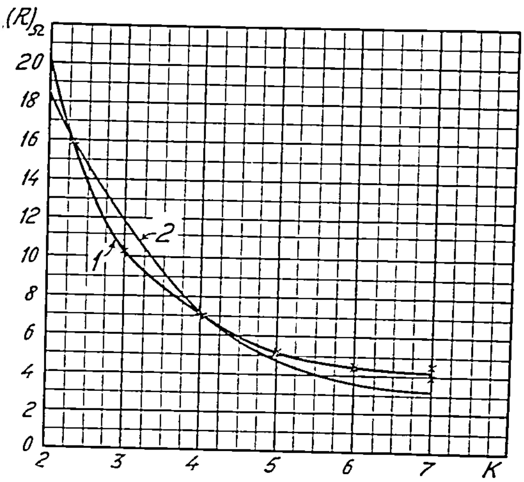

Fig. 6—Resistance of a triangular antenna vs. k, where the loop perimeter is 60 meters.
Curve 1, experimentally determined.
Curve 2, calculated with $A=17$.

though not all of the material obtained from the experiment is reproduced in this paper we may say, however, that the curves here are typical and that all of the deductions concerning these curves are true also for the curves not mentioned here.

When the above-mentioned experimental curves are examined one immediately notices a pretty abrupt increase of R with a decrease of $k=\lambda/P$ which takes place in the range $k=6$ to 2. The nature of this phenomenon might be explained by Fig. 5. Curves 1 and 2, shown in this figure, were taken in the same range of wave lengths, the antenna perimeter of component curve (1) being 120 meters, and the range being $k=2$ to 4.5. The range for curve (2), $P=60$ meters, is $k=$ 4 to 9.

In spite of the sharp ascent of curve (1) the ordinates of curve (2) with decreasing k, increase comparatively slowly. It is evident, then,

that the change of the wave length is not as important as the change of the ratio k of the wave length to the perimeter and the change of that part of the maximum antenna current (I_M) which flows in the external medium. With $k=6$ to 7 the distribution of current becomes practically uniform and the currents that are completed through the external medium become almost equal to zero. In the range of $k=6$ to 2, with decrease of k, these currents increase sharply and contribute to the increase of R.

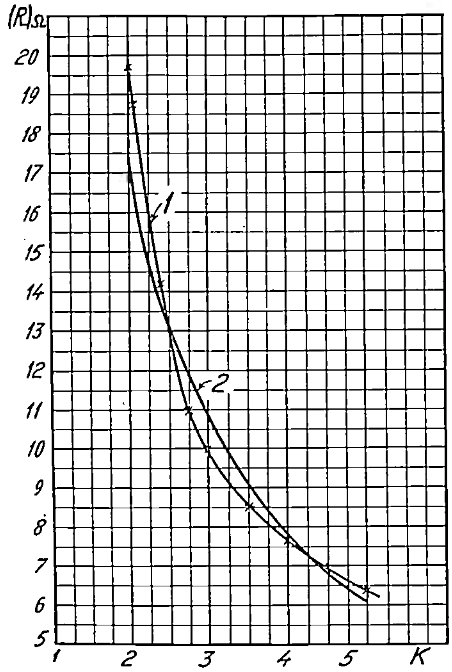

Fig. 7—Resistance of a five-sided antenna.
Curve 1, experimentally determined.
Curve 2, calculated with $A=10$ and radiation resistance included.

Evidently the reason for the increase of R is in the increase of earth losses with decreased k and increase of currents completed through the external medium.

It is necessary to note that this conclusion is not based on the data of a single case since the curves in Fig. 5 are typical.

Let us continue the analysis of experimental data. It is fairly well known that among parasitical losses in open antennas, the losses in the earth due to dielectric hysteresis are most important (formula by M. W. Schouleikin, $R_c=A\lambda/\lambda_0$). It is only natural to assume the existence of parasitical losses of the same character in closed antennas as well.

In the above relation we had as the dielectric loss in a closed antenna

$$R_C = A\Phi(k).$$

Having as our problem the ascertaining of the nature of R and the obtaining of a formula for rough calculations only, as a first approximation we may neglect the existence of any other components (the resistance R_Σ of radiation in a given case is small), apart from R_c and R_Ω (R_Ω is the loss in heating of the wires). The curve R_Ω of an antenna with P equal to 120 meters which was obtained by calculations is represented in Fig. 5 (see curve 1′). Further calculations show that with $A=10$ we obtain the theoretical curve of R (Fig. 5, curve 3) which is fairly close to the experimental curve.

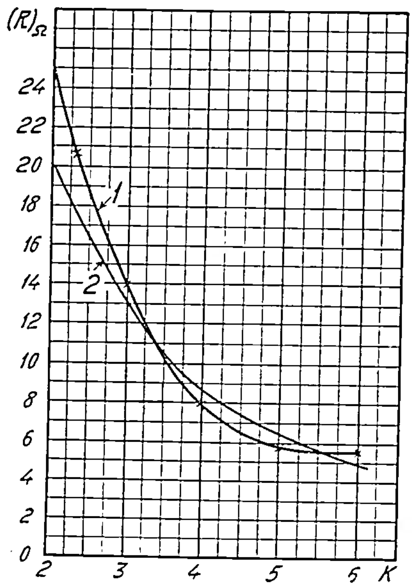

Fig. 8—Resistance of a triangular antenna vs. k, where the loop perimeter is 170 meters.
Curve 1, experimentally determined.
Curve 2, calculated with $A=17$.

This permits us to make an assumption as to the possibility of constructing for R an empirical formula

$$R = R_\Sigma + R_\Omega + R_C = R_\Sigma + R_\Omega + A\Phi(k). \qquad (22)$$

The analysis of a number of experimental curves (Figs. 6, 7, and 8, together with others not included in this paper) shows that it is always possible to select a value A in the region $A=10$ to 20 such that the theoretical curve drawn from (22) will satisfactorily coincide with a curve obtained experimentally for closed antennas whose lower wires are sufficiently distant from the ground (the height of the lower wire above the ground is not less than twenty-five meters and about twenty per cent of the mast height).

As long as all the experimental data are represented by the formula $R=R_\Sigma+R_\Omega+A\Phi(k)$ with $A=10$ to 20 we may consider that the re-

sistance of a closed antenna consists fundamentally of the resistance of the losses in wire heating, resistance in earth losses in dielectric hysteresis, and radiation resistance (the latter in most cases might be disregarded in comparison with $(R_\Omega+R_C)$).

For a rough definition of R the following formula might be recommended:

$$R = R_\Omega + R_\Sigma + 15\Phi(k). \tag{23}$$

For conservative calculations, the following formula may be used:

$$R = R_\Omega + R_\Sigma + 20\Phi(k). \tag{24}$$

For the curves of Fig. 6 (triangular antenna with perimeter $P=60$ meters) the height of suspension of the lower wire above the ground is 2.5 meters (the full height of a mast is 10.1 meters) satisfactory correlation of calculation and experiment is obtained at $A=17$. Fig. 7 (five-sided antenna) where the radiation resistance is taken into account (calculating roughly by $R_\Sigma=1600\ h_e^2/\lambda^2$) will be satisfied by $A=10$. For Fig. 8, ($P=170$ meters, triangular antenna, height of mast 25 meters; suspension height of lower wire 4.5 meters) a value of $A=17$ was used in calculating curve 2.

The antenna and curve of resistance of a closed antenna which was used by Jackson and Bailey[5] are represented in Figs. 9 and 10. Fig. 10 gives their curve (see their Fig. 31) drawn in our co-ordinates.

Considering the lack of any data on the material of the wire of the antenna and on the method which was used in measuring its resistance, we assume that the measured resistance is referred to the current at the end; i.e., it represents the "apparent active resistance."

In Section II, equation (13), we obtained $R_k=RF(k)$, where $F(k)$ is to be taken from Fig. 3. By assuming $A=20$ and $R_\Omega=4\Omega$ and making the calculation of the antenna resistance according to the formula

$$R_k = RF(k) = [4 + 20\phi(k)]F(k)$$

the theoretical curve will be fairly close to the experimental one. For an antenna having a perimeter of 200 meters Murphy and Wolf[6] obtained at $\lambda=1000$ meters, a resistance equal to eleven ohms. Assuming that this resistance is referred to the current at the ends of antenna, we can calculate it by the formula

$$R_k = [R_\Omega + \phi(k)]F(k).$$

Assuming at the same time that $A=15$ and (due to lack of accurate data) $R_\Omega=3\Omega$

[5] Jackson and Bailey, Proc. I.R.E., vol. 18, pp. 2059–2101; December, (1930).

[6] *Jour. Soc. Automotive Eng.*, vol. 19, p. 209; September, (1926).

$$R = [3 + 15\phi(5)]F(5) = [3 + 15 \times 0.183]1.89 = 10.85\Omega.$$

As R_Ω is evidently not less than one ohm and not more than five ohms the error here is not more than two ohms; i.e., not more than eighteen per cent which is permissible in our premises.

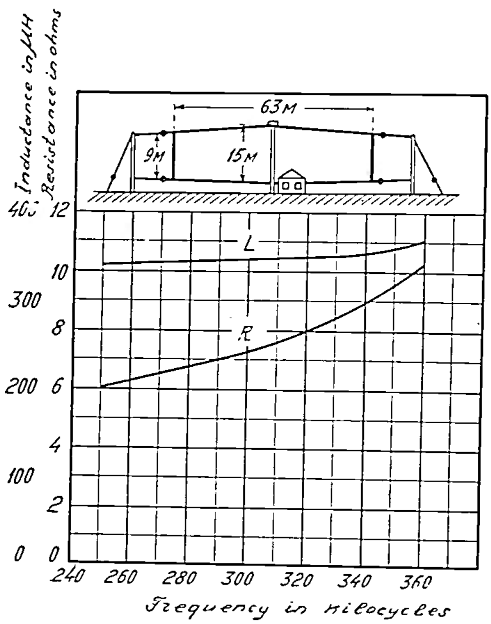

Fig. 9—Sketch of radio range beacon loop with curves showing measured resistance and inductance.

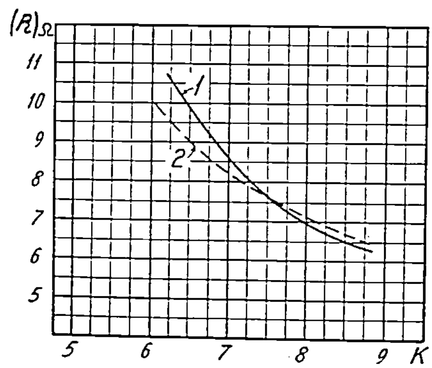

Fig. 10—Curve 1 is the measured resistance curve from Fig. 9 replotted against k as abscissa. Curve 2 shows the calculated values.

We wish to note once more that formulas which we recommended for rough calculation and definition of range R are good only when the lower wires of an antenna are sufficiently distant from the ground, that is, when the height of suspension of these wires is not less than twenty-five meters and about twenty per cent of the mast height. Nonobservance of

the latter may cause an important increase of R especially with k close to 2 (see Fig. 3).

By reason of the aforesaid, it may be asserted that the fundamental component of antenna resistance of a closed antenna is the resistance R_c, the equivalent of the loss in dielectric hysteresis in the earth. This assertion leads to the conclusion that R may be calculated by the formula

$$R = R_\Omega + R_\Sigma + A\Phi(k).$$

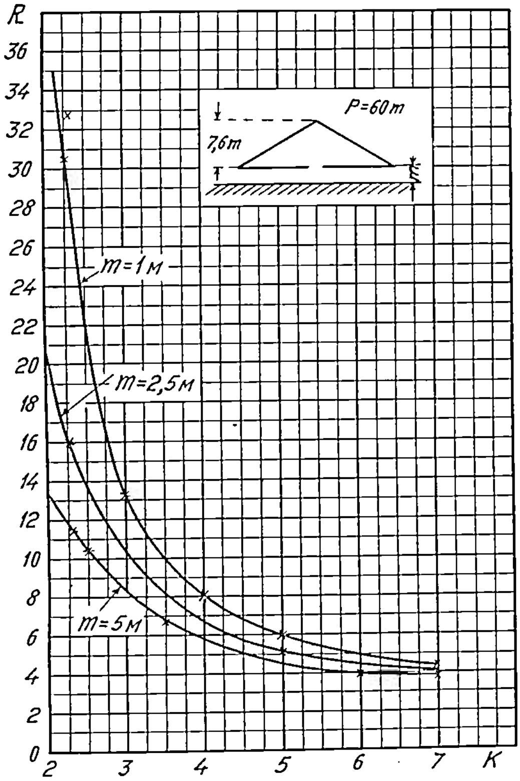

Fig. 11—Measured resistance of the loop shown in the sketch for different heights of the lower wires above ground, showing the rapid decrease in dielectric loss for small values of k as the lower wires are raised.

But there are not sufficient data to determine the nature of the coefficient A and the nature of its dependence on the quality of the ground, configuration of closed antenna, etc.

Therefore the empirical formula (22) may serve only as an understanding of the physical nature of R and for very rough calculations.

Fig. 11 shows the measured resistance of the loop indicated in the sketch for different heights of the lower wires above ground. It shows how the dielectric losses rapidly decrease as the wires are raised, especially for small values of k.

V. Some Considerations on the Selection of the Perimeter and other Dimensions of a Closed Antenna

In Section I, in assuming the requirements for the steady operation of a closed antenna and a beacon as a whole, we have confined ourselves in the selection of the perimeter of a closed antenna by the condition $k \geqq 2$. In the same paragraph we have pointed out that the magnitude $h_e/\sqrt{R}$ which equals the meter-ampere moment of the antenna current, at P_A = one watt, in the direction of maximum radiation, must have its maximum at a value of k close to 2.

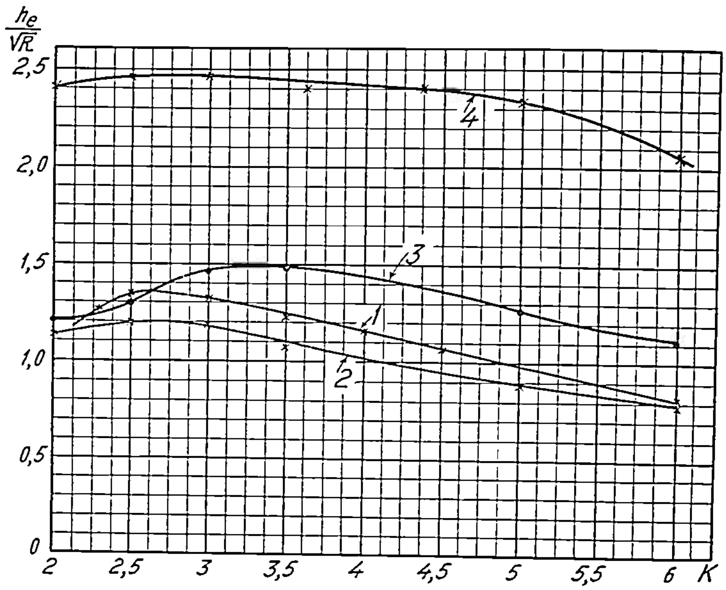

Fig. 12—Curves showing the relation between $h_e/\sqrt{R}$ vs. k, where h_e is the effective height of the loop.

Curve 1, for perimeter of 120 meters.
Curve 2, for perimeter of 60 meters.
Curve 3, for perimeter of 110 meters, five-sided loop, (see Fig. 7) height of mast, 17.5 meters, mean height of the lower wires above ground, 3 meters.
Curve 4, for perimeter of 170 meters, triangular loop (see Fig. 8).

As this magnitude may be of use as one of the criteria of the effectiveness of the antenna, it will be of interest to find out how abruptly the curve falls off $s = h_e/\sqrt{R} = \phi(k) = \psi(k)$ in the vicinity of the maximum and at what value of k the maximum is obtained.

We shall abstain from a theoretical examination of this problem and restrict ourselves to showing several curves of $h_e/\sqrt{R} = \phi(k)$ obtained experimentally.

In Fig. 12 such curves for antennas are represented to which the previous figures are related. In order to construct these curves, experimental values of R were used, and the values of h_e were calculated by formulas in our previous article.[1]

All of the curves cited here are typical and a number of curves not shown do not differ from them fundamentally. The curves $h_e/\sqrt{R}$ for closed antennas are characterized by the presence of a sufficiently blunt maximum at $k=2.5$ to 3.5. For the range of $k=2$ to 4.5 and in some cases for the range of $k=2$ to 6, the value $h_e/\sqrt{R}$ might be considered as almost constant.

In comparing curves 1 and 2 (they correspond to antennas having perimeters of 120 and 60 meters, respectively, with the same mast height and suspension height of the lower cables) we find that at a

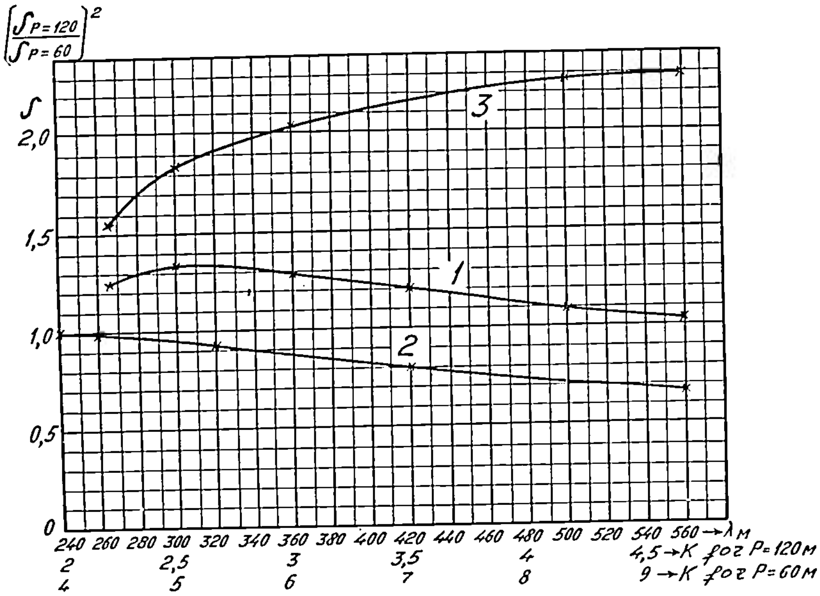

Fig. 13—Curves showing effect of the loop perimeter on the efficiency of radiation. The loop perimeters are 120 meters for curve 1, and 60 meters for curve 2. The ordinates for curves 1 and 2 are proportional to the effective height of the loops. The ordinates of curve 3 are proportional to the power gain due to increasing the loop perimeter from 60 to 120 meters.

given value of k, the values $h_e/\sqrt{R}$ for the curves differ little one from another. Therefore, for a given value of λ, the antennas with greater perimeter which correspond to these curves will be more efficient and consequently, at a given value of λ, are preferable to antennas which have k smaller. Once more we have to note that in the range $k=2$ to 6, at reduced k, $h_e/\sqrt{R}$ is increasing in most cases.

If the selection is made of too small a value of k (of the rate 1), it is necessary, as it has been already pointed out, to expect a decrease of $h_e/\sqrt{R}$ because h_e decreases while R rises continuously.

These conclusions are confirmed by the data in Fig. 13, representing the dependency of $S=h_e/\sqrt{R}$ on λ. For the two closed antennas with which we are familiar, namely those for which $P=120$ meters

and $P=60$ meters, the antenna having the perimeter of 120 meters has a higher value of S throughout the whole range of wavelengths from 240 to 560 meters. Curve 3 of Fig. 13 shows the dependence of $[(Sp=120\text{m})/(Sp=60\text{ m})]^2$ on λ. As the power in the antenna, other things being equal, is proportional to S^2, curve 3 shows to what degree the power of the generator may be diminished due to the change from a small antenna ($P=60$ meters) to an antenna with a larger perimeter ($P=120$ meters) without changing the current moment of the antenna.

As long as the curves cited here are typical, we note that it is necessary to take, if possible, a perimeter of the antenna which would give, with the shortest wave of the given range, $k \cong 2$.

When such a selection of the perimeter is inconvenient, because of constructional considerations, and we have to select a smaller perimeter, then it is necessary to take the perimeter of the closed antenna as large as possible.

VI. Some Methods of Increasing the Efficiency Factor of Closed Antennas

Dealing with radio beacons, we note that the efficiency factor of the closed antenna is usually very small and amounts to a few per cent at best, since the values usually met are $k>2$, and the radiation resistance R_Σ has the order of magnitude of tenths of an ohm.

However, operating with $k \leqq 2$ and using special methods in order to diminish parasitic losses, it is possible to obtain an important increase of the efficiency factor of a closed antenna made by the authors in 1930.

One possible means for attaining this object is to place a tuned or untuned screen between the closed antenna and the ground. Fig. 14 represents a sketch of an antenna and screen as well as curves for R, one with a screen, another without it, which illustrate the expressed statement. The point marked a ($R=7.7\ \Omega$ with $k=2.35$) was obtained by tuning the screen. Fig. 14 shows that by receiving with the screen, the currents of the closed antenna which otherwise are completed through the external medium, we may greatly diminish the earth losses (in this case more than twice).[7]

This method is not of great practical value to radio beacons, since the range of beacons with closed antennas is limited in practice by other factors (night effect) to a greater degree than by the small efficiency of the antenna.

The possibility of reception using a closed antenna with a mast

[7] See also R. H. Barfield and N. A. Mjasoedoff, *Jour. I.E.E.* (*London*), vol. 76, p. 48.

height ranging around $\lambda/10$ and efficiency factor ranging from forty to fifty per cent is of some interest, independently of its use as a radio beacon. In some cases the closed antenna with a relatively high efficiency factor (particularly in co-operation with an open antenna for radiation with a cardioid diagram) might serve as a very simple but sufficiently effective radiating antenna, operating at medium and

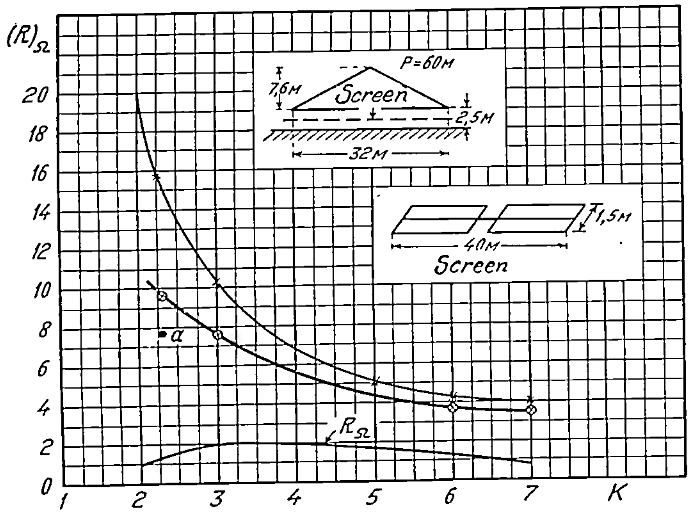

Fig. 14—Sketch showing screen under closed loop for decreasing ground losses and curves showing measured decrease in resistance due to use of the screen.
Upper curve, resistance when no screen was used.
Middle curve, resistance with untuned screen.
Point *a*, resistance with tuned screen.
Lower curve, loop conductor losses alone.

medium high frequencies. Intensive radiation of a closed antenna upwards could be used at nighttime.

Especially great possibilities could be derived from a closed antenna in radio transmitters with a combined wave range if, for the short-wave range, it is excited by high harmonics.[8]

Acknowledgment

The authors express their sincerest thanks to Professor F. W. Grover of Union College for his kind interest, aid, and corrections in this work.

[8] V. I. Bashenoff, U.S.S.R. Patent No. 28,551.

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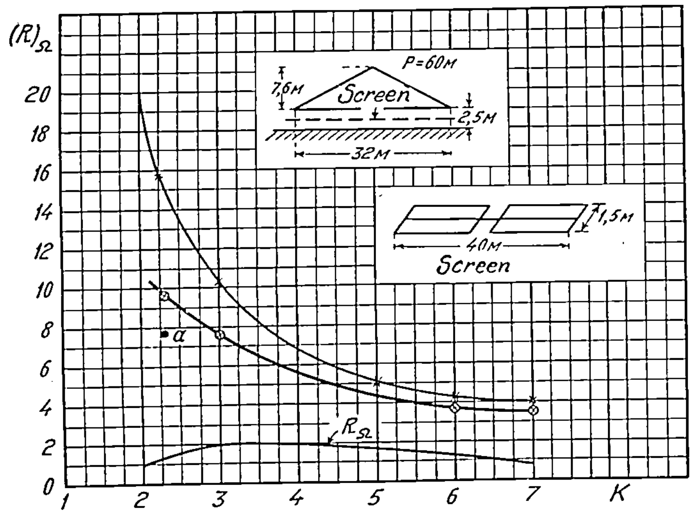

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A STUDY OF THE ELECTROMAGNETIC FIELD IN THE VICINITY OF A RADIATOR*

By
F. R. Stansel
(Bell Telephone Laboratories, Inc., Whippany, New Jersey)

Summary—*The complete equations for the electromagnetic field of an infinitesimal current element are given. The integration of these equations is considered for the case of a finite radiator having an empirical current distribution. Tables are included to facilitate computation and consideration is given to difference in phase of the current in various portions of the radiator.*

PROBLEMS in radio engineering involving the radiation and propagation of electromagnetic waves are frequently solved by the use of approximate expressions for the electromagnetic field which are, in general, not valid in a region less than one wave length

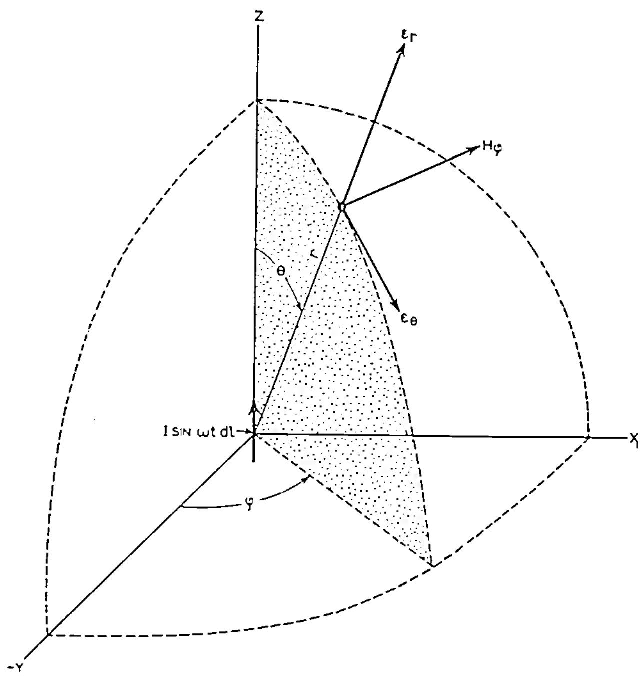

Fig. 1—Co-ordinate system.

from the radiator. When it becomes necessary to compute the electromagnetic field in the vicinity of the radiator, more generalized equations for the electromagnetic field must be employed.

* Decimal classification: R111.2. Original manuscript received by the Institute, June 26, 1935; revised manuscript received by the Institute, February 14, 1936.

These generalized equations may be derived by use of the Lorentz retarded vector and scalar potentials. Assuming a radiating element of infinitesimal length dl carrying a sinusoidal current of the form $I \sin \omega t$ located at the center of the co-ordinate system shown in Fig. 1, the complete equations for the electromagnetic field at any point are[1]

$$\epsilon_r = 376.76 \frac{I}{r} \frac{dl}{\lambda} \cos \theta [A \cos \omega t + B \sin \omega t] \tag{1}$$

$$\epsilon_\theta = 188.38 \frac{I}{r} \frac{dl}{\lambda} \sin \theta [C \cos \omega t + D \sin \omega t] \tag{2}$$

$$H_\phi = \frac{I}{2r} \frac{dl}{\lambda} \sin \theta [F \cos \omega t + G \sin \omega t] \tag{3}$$

in which the factors, A, B, C, D, F, and G are defined as follows:

$$\left.\begin{aligned} A &= -\beta \sin \alpha - \beta^2 \cos \alpha \\ B &= \beta \cos \alpha - \beta^2 \sin \alpha \\ C &= (1-\beta^2) \cos \alpha - \beta \sin \alpha \\ D &= (1-\beta^2) \sin \alpha + \beta \cos \alpha \\ F &= \cos \alpha - \beta \sin \alpha \\ G &= \sin \alpha + \beta \cos \alpha \end{aligned}\right\} \tag{4}$$

and,

$$\alpha = 1/\beta = 2\pi r/\lambda. \tag{5}$$

The above equations are expressed in the ohm-volt-centimeter-second system of units. In this system the electric field intensity is expressed in volts per centimeter and the magnetic field intensity in amperes per centimeter.

The computation of the field near a finite radiator is generally simplified by transforming (1), (2), and (3) to a cylindrical co-ordinate system. These equations may be still further generalized by assuming that the current has a phase angle; that is, that the current is of the form $I \sin (\omega t - \psi)$. When these assumptions are introduced the generalized radiation equations become

$$\epsilon_1 = \frac{Idl}{\lambda^2} \sin 2\theta [F_1 \cos \omega t + F_2 \sin \omega t] \tag{6}$$

[1] *See* Page and Adams, "Principles of Electricity," Chap. XVI; J. A. Fleming, "Principles of Electric Wave Telegraphy and Telephony," Chap. V; and G. W. Pierce, "Electric Oscillations and Electric Waves," Book II, Chap. VIII. See also the articles listed under reference No. 1 of Bibliography.

$$\epsilon_2 = \frac{Idl}{\lambda^2}[(F_3 + F_1 \cos 2\theta) \cos \omega t + (F_4 + F_2 \cos 2\theta) \sin \omega t] \tag{7}$$

$$H = \frac{Idl}{\lambda^2} \sin \theta [F_5 \cos \omega t + F_6 \sin \omega t]. \tag{8}$$

Here ϵ_1 is the electric field component perpendicular to and directed away from the current element and ϵ_2 is the electric field component parallel to and in the same direction as the current element. H is the magnetic field component previously expressed by (3).

The functions F_1 through F_6 are defined as

$$\left.\begin{aligned} F_1 &= 94.192 \frac{\lambda}{r}[\cos \delta - 3\beta(\sin \delta + \beta \cos \delta)] \\ F_2 &= 94.192 \frac{\lambda}{r}[\sin \delta + 3\beta(\cos \delta - \beta \sin \delta)] \\ F_3 &= 94.192 \frac{\lambda}{r}[- \cos \delta - \beta(\sin \delta + \beta \cos \delta)] \\ F_4 &= 94.192 \frac{\lambda}{r}[- \sin \delta + \beta(\cos \delta - \beta \sin \delta)] \\ F_5 &= \frac{\lambda}{2r} (\cos \delta - \beta \sin \delta) \\ F_6 &= \frac{\lambda}{2r} (\sin \delta + \beta \cos \delta) \end{aligned}\right\} \tag{9}$$

in which,

$$\delta = \alpha + \psi. \tag{10}$$

These six quantities are functions only of the distance from the radiator and the phase shift of the exciting current, and are tabulated in Tables I through VI for phase shifts up to 180 degrees. For greater phase shifts these tables may be extended by the relation

$$F_n(r, \psi + 180°) = - F_n(r, \psi). \tag{11}$$

The electromagnetic field of a radiator of finite dimensions is obtained by summing the effects of the infinitesimal elements of which the radiator may be assumed to be composed.[2] If the distribution of the current along the radiator can be expressed mathematically, the field components can be expressed in terms of definite integrals. These

[2] If the radiator is near the ground, reflection from the ground must also be taken into account. This is usually done by introducing an electric image. *See* Terman, "Radio Engineering," page 497. See also references Nos. 1 and 3 of bibliography for the case in which the ground is an imperfect conductor.

may be integrated by the usual methods or may be evaluated by the use of integral functions whose values have been tabulated.[3]

An alternative method is to integrate graphically. This method is specially advantageous when the current distribution does not follow a simple mathematical form or is given in the form of an empirical curve. The labor in a computation of this type may be shortened by use of Tables I through VI. The following example shows the application of this method.

Example. Given a half wave length dipole. The current distribution along this radiator is assumed to follow a sine wave having a value I_0 at the current loop (that is, $i = I_0 \sin 2\pi l/\lambda \sin \omega t$). Find the field components on the perpendicular bisector at a distance of one-half wave length from the dipole.

From the symmetry of the problem it is apparent that there is no ϵ_1 component at this point. The increments of this component contributed by the upper half of the radiator exactly cancel the increments contributed by the lower half due to the reversal in the sign of $\sin 2\theta$ in (6).

The electric component parallel to the radiator, that is ϵ_2, is equal to the sum of two integrals; viz,

$$\epsilon_2 = \frac{1}{\lambda^2}\int_0^{l=\lambda/2} I[F_3 + F_1 \cos 2\theta]dl \cos \omega t + \frac{1}{\lambda^2}\int_0^{l=\lambda/2} I[F_4 + F_2 \cos 2\theta]dl \sin \omega t. \tag{12}$$

To evaluate the first of these integrals take a number of points along the dipole (it will facilitate the later application of Simpson's rule if an odd number of points including the two extremities are taken) and at these points compute the value of I, r, θ, $\cos 2\theta$. Read the values of F_1 and F_3 from Tables I and III. As the current is in phase throughout this radiator the values used are those in the $\psi = 0$ column. The values of these quantities are

l	I	r	θ	$\cos 2\theta$	F_1	F_3
0λ	0	0.559λ	116°34′	−0.6000	− 69.6	186
0.05λ	$0.309\ I_0$	0.537λ	111°48′	−0.7242	− 82.7	197
0.10λ	$0.588\ I_0$	0.521λ	106°42′	−0.8349	−106	203
0.15λ	$0.809\ I_0$	0.509λ	101°19′	−0.9230	−121	206
0.20λ	$0.951\ I_0$	0.502λ	95°43′	−0.9802	−128	207
0.25λ	I_0	0.500λ	90°00′	−1.0000	−131	207
0.30λ	$0.951\ I_0$	0.502λ	84°17′	−0.9802	−128	207
0.35λ	$0.809\ I_0$	0.509λ	78°41′	−0.9230	−121	206
0.40λ	$0.588\ I_0$	9.521λ	73°18′	−0.8349	−106	203
0.45λ	$0.309\ I_0$	0.537λ	68°12′	−0.7242	− 82.7	197
0.50λ	0	0.559λ	63°26′	−0.6000	− 69.6	186

[3] The most important of these functions are the sine-integral $[Si(x)]$ and cosine-integral $[Ci(x)]$ functions. For an example of their use see S. Ballantine, "On radiation resistance of a simple vertical antenna at wavelength below the fundamental," Proc. I.R.E., vol. 12, pp. 823–832; December, (1924). For tables of these functions see references Nos. 8 through 10 of the bibliography.

Next compute the value of

$$I(F_3 + F_1 \cos 2\theta)$$

at each point on the dipole and plot the expressions as a function of the distance along the dipole as shown in Fig. 2. The value of the integral

$$\int_0^{l=\lambda/2} I[F_3 + F_1 \cos 2\theta] dl$$

is the area under this curve between the abscissas 0 and $\lambda/2$, or the shaded area in Fig. 2.

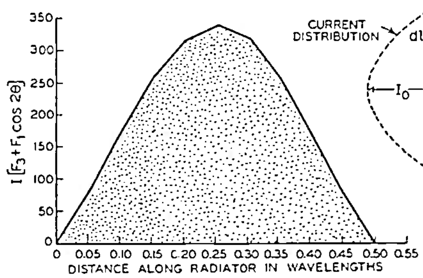

Fig. 2—Example of computation of the field by graphical integration.

This area is then evaluated by means of Simpson's rule, or any other suitable method. In this case the area, and hence the value of the integral, is 99.9 I_0/λ.

The second integral in (12) is evaluated in a like manner and the final result for ϵ_2 obtained as

$$\epsilon_2(\text{volts per cm}) = 99.9 \frac{I_0}{\lambda} \cos \omega t + 38.9 \frac{I_0}{\lambda} \sin \omega t.$$

In a like manner the magnetic field components may be evaluated. They are

$$H(\text{amps per cm}) = -0.301 \frac{I_0}{\lambda} \cos \omega t - 0.1140 \frac{I_0}{\lambda} \sin \omega t.$$

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TABLE I—F_1

r/λ	ψ = 0	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	−58230	−55380	−47100	−34220	−17990	3.985	18000	34230	47110	55380	58230
0.10	−7673	−7292	−6198	−4497	−2356	15.31	2385	4522	6216	7302	7673
0.15	−2495	−2362	−1999	−1440	−739.6	32.80	802.0	1493	2037	2383	2495
0.20	−1200	−1124	−938.4	−660.5	−318.0	55.59	423.8	750.5	1004	1159	1200
0.25	−719.6	−659.2	−534.3	−357.2	−145.0	81.33	299.7	488.7	630.0	709.5	719.6
0.30	−490.3	−433.0	−333.3	−200.9	−48.87	107.9	254.2	375.5	460.1	499.7	490.3
0.40	−265.2	−204.4	−123.6	−30.73	65.19	154.7	229.1	281.1	305.5	300.1	265.2
0.50	−131.1	−59.69	−0.3408	68.46	130.6	179.9	211.6	222.6	211.8	180.1	131.1
0.60	−26.77	28.27	80.54	124.9	157.1	173.9	173.6	156.4	123.8	79.18	26.77
0.70	52.38	91.78	121.9	141.1	145.9	136.5	113.7	79.76	38.03	−7.295	−52.38
0.80	98.90	117.8	125.2	120.4	103.8	76.96	42.64	4.136	−34.77	−70.27	−98.90
0.90	109.4	107.4	94.84	73.04	44.09	10.83	−23.50	−55.52	−82.11	−100.7	−109.4
1.0	87.03	68.88	43.98	14.77	−15.88	−44.97	−69.67	−87.54	−96.85	−96.67	−87.03
1.2	−6.727	−31.23	−52.68	−68.97	−78.51	−80.36	−74.35	−61.06	−41.79	−18.44	6.727
1.4	−65.81	−68.60	−64.67	−54.42	−38.83	−19.45	1.838	22.95	41.81	56.58	65.81
1.6	−35.89	−19.36	−0.9440	17.57	34.36	47.79	56.54	59.76	57.12	48.90	35.89
1.8	28.99	41.27	49.50	52.89	51.10	44.31	33.18	18.81	2.590	−13.88	−28.99
2.0	46.20	40.47	30.77	18.06	3.584	−11.24	−24.97	−36.25	−43.99	−47.41	−46.20
2.5	−37.22	−33.17	−25.88	−16.06	−4.658	7.196	18.34	27.70	34.34	37.62	37.22
3.0	31.13	28.06	22.31	14.26	4.868	−4.997	−14.37	−22.34	−28.12	−31.15	−31.13

Note: The values of ψ in Tables I through VI are the phase shift at intervals 0.05λ along a radiator.

TABLE II—F_2

r/λ	ψ = 0	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	−3.985	−18000	−34230	−47110	−55380	−58230	−55380	−47100	−34220	−17990	3.985
0.10	−15.31	−2385	−4522	−6216	−7302	−7673	−7292	−6198	−4497	−2356	15.31
0.15	−32.80	−802.0	−1493	−2037	−2382	−2495	−2362	−1999	−1440	−739.6	32.80
0.20	−55.59	−432.8	−750.7	−1004	−1159	−1200	−1124	−938.4	−660.5	−318.0	55.59
0.25	−81.33	−299.7	−488.7	−630.0	−709.5	−719.6	−659.2	−534.3	−357.2	−145.0	81.33
0.30	−107.9	−254.2	−375.5	−460.1	−499.7	−490.3	−433.0	−333.3	−200.9	−48.87	107.9
0.40	−154.7	−229.1	−281.1	−305.5	−300.1	−265.2	−204.4	−123.6	−30.73	65.19	154.7
0.50	−179.9	−211.6	−222.6	−211.8	−180.1	−131.1	−59.69	−0.3408	68.46	130.6	179.9
0.60	−173.9	−173.6	−156.4	−123.8	−79.18	−26.77	28.27	80.54	124.9	157.1	173.9
0.70	−136.5	−113.7	−79.76	−38.03	7.295	52.38	91.78	121.9	141.1	145.9	136.5
0.80	−76.96	−42.64	−4.136	34.77	70.27	98.90	117.8	125.2	120.4	103.8	76.96
0.90	−10.83	23.50	55.52	82.11	100.7	109.4	107.4	94.84	73.04	44.09	10.83
1.0	44.97	69.67	87.54	96.85	96.67	87.03	68.88	43.98	14.77	−15.88	−44.97
1.2	80.36	74.35	61.06	41.79	18.44	−6.727	−31.23	−52.68	−68.97	−78.51	−80.36
1.4	19.45	−1.838	−22.95	−41.81	−56.58	−65.81	−68.60	−64.67	−54.42	−38.83	−19.45
1.6	−47.49	−56.54	−59.76	−57.12	−48.90	−35.89	−19.36	−0.9440	17.57	34.36	47.79
1.8	−44.31	−33.18	−18.81	−2.590	13.88	28.99	41.27	49.50	52.89	51.10	44.31
2.0	11.24	24.97	36.25	43.99	47.41	46.20	40.47	30.77	18.06	3.584	−11.24
2.5	−7.196	−18.34	−27.70	−34.34	−37.62	−37.22	−33.17	−25.88	−16.06	−4.658	7.196
3.0	4.997	14.37	22.34	28.12	31.15	31.13	28.06	22.31	14.26	4.868	−4.997

TABLE III—F_3

$\frac{r}{\lambda}$	ψ										
	0	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	−21800	−20490	−17180	−12180	−5996	777.5	7475	13440	18090	20970	21800
0.10	−3574	−3169	−2454	−1499	−397.4	743.3	1811	2659	3328	3628	3574
0.15	−1324	−1046	−666.5	−221.2	245.6	688.3	1064	1335	1475	1472	1324
0.20	−594.1	−374.8	−118.9	148.9	402.0	615.7	769.2	847.4	842.6	755.3	594.1
0.25	−239.9	−64.50	117.2	287.4	429.4	529.5	577.7	569.3	505.3	391.7	239.9
0.30	−34.08	40.22	227.6	331.2	402.3	434.1	423.4	371.2	282.7	166.6	34.08
0.40	165.6	230.5	272.8	288.4	275.7	236.1	173.4	93.69	4.821	−84.52	−165.6
0.50	207.5	215.8	203.1	170.5	121.1	59.96	−7.083	−73.43	−132.6	−179.1	−207.5
0.60	160.4	101.7	91.53	41.64	−12.32	−65.08	−111.5	−146.9	−168.0	−172.7	−160.4
0.70	72.90	30.59	−14.63	−58.43	−96.51	−125.1	−141.5	−144.0	−132.5	−107.9	−72.90
0.80	−15.55	−52.99	−85.26	−109.2	−122.4	−123.6	−112.8	−90.90	−60.10	−23.42	−15.55
0.90	−76.44	−96.93	−107.9	−108.4	−98.20	−78.41	−50.95	−18.51	15.75	48.47	76.44
1.0	−96.58	−96.48	−86.94	−68.90	−44.10	−14.99	15.59	44.64	69.32	87.22	96.58
1.2	−34.58	−10.41	14.78	38.53	58.50	72.75	79.87	79.18	70.74	55.37	34.58
1.4	50.64	62.45	68.15	67.18	59.63	46.25	28.33	7.648	−13.79	−33.87	−50.64
1.6	51.54	39.68	23.94	5.856	−12.80	−30.21	−44.66	−54.73	−59.45	−58.35	−51.54
1.8	−11.90	−27.26	−39.95	−48.73	−52.74	−51.86	−45.39	−34.74	−20.70	−4.627	11.90
2.0	−47.39	−46.23	−40.55	−30.89	−18.21	−3.748	11.08	24.83	36.14	43.92	47.39
2.5	37.83	36.72	32.01	24.18	13.97	2.399	−9.409	−20.30	−29.19	−35.24	−37.83
3.0	−31.49	−30.46	−26.43	−19.85	−11.31	−1.666	8.145	17.16	24.49	29.43	31.49

TABLE IV—F_4

$\frac{r}{\lambda}$	ψ										
	0°	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	−777.5	−7475	−13440	−18090	−20970	−21800	−20490	−17180	−12180	−5996	777.5
0.10	−743.3	−1811	−2659	−3328	−3628	−3574	−3169	−2454	−1499	−397.4	743.3
0.15	−688.3	−1064	−1335	−1475	−1472	−1324	−1046	−666.5	−221.2	245.6	688.3
0.20	−615.7	−769.2	−847.4	−842.6	−755.3	−594.1	−374.8	−118.9	148.9	402.0	615.7
0.25	−529.5	−577.7	−569.3	−505.3	−391.7	−239.9	−64.50	117.2	287.4	429.4	529.5
0.30	−434.1	−423.4	−371.2	−282.7	−166.6	−34.08	40.22	227.6	331.2	402.3	434.1
0.40	−236.1	−173.4	−93.69	−4.821	84.52	165.6	230.5	272.8	288.4	275.7	236.1
0.50	−59.96	7.083	73.43	132.6	179.1	207.5	215.8	203.1	170.5	121.1	59.96
0.60	65.08	111.5	146.9	168.0	172.7	160.4	101.7	91.53	41.64	−12.32	−65.08
0.70	125.1	141.5	144.0	132.5	107.9	72.90	30.59	−14.63	−58.43	−96.51	−125.1
0.80	123.6	112.8	90.90	60.10	23.42	−15.55	−52.99	−85.26	−109.2	−122.4	−123.6
0.90	78.41	50.95	18.51	−15.75	−48.47	−76.44	−96.93	−107.9	−108.4	−98.20	−78.41
1.0	14.99	−15.59	−44.64	−69.32	−87.22	−96.58	−96.48	−86.94	−68.90	−44.10	−14.99
1.2	−72.75	−79.87	−79.18	−70.74	−55.37	−34.58	−10.41	14.78	38.53	58.50	72.75
1.4	−46.25	−28.33	−7.648	13.79	33.87	50.64	62.45	68.15	67.18	59.63	46.25
1.6	30.21	44.66	54.73	59.45	58.35	51.54	39.68	23.94	5.856	−12.80	−30.21
1.8	51.86	45.39	34.74	20.70	4.627	−11.90	−27.26	−39.95	−48.73	−52.74	−51.86
2.0	3.748	−11.08	−24.83	−36.14	−43.92	−47.39	−46.23	−40.55	−30.89	−18.21	−3.748
2.5	−2.399	9.409	20.30	29.19	35.24	37.83	36.72	32.01	24.18	13.97	2.399
3.0	1.666	−8.145	−17.16	−24.49	−29.43	−31.49	−30.46	−26.43	−19.85	−11.31	−1.666

TABLE V—F_5

$\frac{r}{\lambda}$	ψ										
	0	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	−0.3258	−10.62	−19.87	−27.18	−31.83	−33.36	−31.63	−26.80	−19.35	−10.00	0.3258
0.10	−0.6325	−3.499	−6.023	−7.958	−9.114	−9.377	−8.723	−7.214	−5.000	−2.296	0.6325
0.15	−0.9019	−2.334	−3.537	−4.394	−4.821	−4.776	−4.263	−3.333	−2.077	−0.6179	0.9019
0.20	−1.120	−1.989	−2.665	−3.079	−3.192	−2.992	−2.500	−1.763	−0.8532	0.1400	1.120
0.25	−1.273	−1.829	−2.206	−2.366	−2.296	−2.000	−1.509	−0.8696	−0.1455	0.5929	1.273
0.30	−1.356	−1.695	−1.868	−1.858	−1.667	−1.312	−0.8286	−0.2643	0.3259	0.8842	1.356
0.40	−1.304	−1.343	−1.250	−1.035	−0.7189	−0.3324	0.08675	0.4974	0.8593	1.137	1.304
0.50	−1.000	−0.8527	−0.6219	−0.3303	−0.006288	0.3183	0.6118	0.8453	0.9961	1.049	1.000
0.60	−0.5443	−0.3234	−0.04728	0.2299	0.4865	0.6687	0.8363	0.8609	0.8667	0.7532	0.5443
0.70	−0.06627	0.1624	0.3752	0.5512	0.6733	0.7312	0.7143	0.6291	0.4824	0.2885	0.06627
0.80	0.3114	0.4680	0.5787	0.6328	0.6250	0.5560	0.4325	0.2668	0.07488	−0.1243	−0.3114
0.90	0.5072	0.5587	0.5556	0.4901	0.3917	0.2471	0.07241	−0.09824	−0.2651	−0.4060	−0.5072
1.0	0.5000	0.4509	0.3577	0.2295	0.07882	−0.07958	−0.2302	−0.3583	−0.4513	−0.5001	−0.5000
1.2	0.07620	−0.05526	−0.1813	−0.2896	−0.3696	−0.4134	−0.4167	−0.3792	−0.3042	−0.2002	−0.07620
1.4	−0.3128	−0.3522	−0.3571	−0.3271	−0.2651	−0.1771	−0.07175	0.04060	0.1490	0.2428	0.3128
1.6	−0.2346	−0.1585	−0.06701	0.03109	0.1261	0.2088	0.2711	0.3068	0.3125	0.2876	0.2346
1.8	0.1092	0.1831	0.2392	0.2718	0.2778	0.2566	0.2103	0.1434	0.06248	−0.02456	−0.1092
2.0	0.2500	0.2316	0.1906	0.1309	0.05834	−0.01989	−0.09618	−0.1630	−0.2139	−0.2441	−0.2500
2.5	−0.2000	−0.1863	−0.1543	−0.1073	−0.04969	0.01273	0.07391	0.1279	0.1693	0.1941	0.2000
3.0	0.1667	0.1558	0.1297	0.09081	0.04309	−0.008842	−0.05991	−0.1032	−0.1400	−0.1612	−0.1667

TABLE VI—F_6

$\frac{r}{\lambda}$	ψ										
	0	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°
0.05	33.36	31.63	26.80	19.35	10.00	−0.3258	−10.62	−19.87	−27.18	−31.83	−33.36
0.10	9.377	8.723	7.214	5.000	2.296	−0.6325	−3.499	−6.023	−7.958	−9.114	−9.377
0.15	4.776	4.263	3.333	2.077	0.6179	−0.9019	−2.334	−3.537	−4.394	−4.821	−4.776
0.20	2.992	2.500	1.763	0.8532	−0.1400	−1.120	−1.989	−2.665	−3.079	−3.192	−2.992
0.25	2.000	1.509	0.8696	0.1455	−0.5929	−1.273	−1.829	−2.206	−2.366	−2.296	−2.000
0.30	1.312	0.8286	0.2643	−0.3259	−0.8842	−1.356	−1.695	−1.868	−1.858	−1.667	−1.312
0.40	0.3324	−0.08675	−0.4974	−0.8593	−1.137	−1.304	−1.343	−1.250	−1.035	−0.7189	−0.3324
0.50	−0.3183	−0.6118	−0.8453	−0.9961	−1.049	−1.000	−0.8527	−0.6219	−0.3303	−0.006288	0.3183
0.60	−0.6687	−0.8363	−0.8609	−0.8667	−0.7532	−0.5443	−0.3234	−0.04728	0.2299	0.4865	0.6687
0.70	−0.7312	−0.7143	−0.6291	−0.4824	−0.2885	−0.06627	0.1624	0.3752	0.5512	0.6733	0.7312
0.80	−0.5560	−0.4325	−0.2668	−0.07488	0.1243	0.3114	0.4680	0.5787	0.6328	0.6250	0.5560
0.90	−0.2471	−0.07241	0.09824	0.2651	0.4060	0.5072	0.5587	0.5556	0.4901	0.3917	0.2471
1.0	0.07958	0.2302	0.3583	0.4513	0.5001	0.5000	0.4509	0.3577	0.2295	0.07882	−0.07958
1.2	0.4134	0.4167	0.3792	0.3042	0.2002	0.07620	−0.05526	−0.1813	−0.2896	−0.3696	−0.4134
1.4	0.1771	0.07175	−0.04060	−0.1490	−0.2428	−0.3128	−0.3522	−0.3571	−0.3271	−0.2651	−0.1771
1.6	−0.2088	−0.2711	−0.3068	−0.3125	−0.2876	−0.2346	−0.1585	−0.06701	0.03109	0.1261	0.2088
1.8	−0.2566	−0.2103	−0.1434	−0.06248	0.02456	0.1092	0.1831	0.2392	0.2718	0.2778	0.2566
2.0	0.01989	0.09618	0.1630	0.2139	0.2441	0.2500	0.2316	0.1906	0.1309	0.05834	−0.01989
2.5	−0.01273	−0.07391	−0.1279	−0.1693	−0.1941	−0.2000	−0.1863	−0.1543	−0.1073	−0.04969	0.01273
3.0	0.008842	0.05991	0.1032	0.1400	0.1612	0.1667	0.1558	0.1297	0.09081	0.04309	−0.008842

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In addition to references already cited in footnotes the following references may be of interest to the reader. This list does not include all available material and only lists articles on antennas which contain information on the field near the antenna or the generalized form of the radiation equations.

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(9) British Association for the Advancement of Science, "Mathematical Tables," (1931). Gives the values of $Si(x)$ and $Ci(x)$ to eleven places in small steps up to $x=40$.

(10) Jahnke und Emde, "Funktionentafeln mit Formeln und Kurven." Gives the values of $Si(x)$ and $Ci(x)$ to four places in small steps up to $x=5$, in steps of unity up to $x=15$ and in steps of five up to $x=100$. Also gives some higher values.

Proceedings of the Institute of Radio Engineers
Volume 24, Number 5 *May, 1936*

BOOK REVIEWS

"Your Invention—How to Protect and Merchandise It," by Elmore B. Lyford, 210 Pages. Radio and Technical Publishing Company, 45 Astor Place, New York City, 1935. Price $1.50.

This book is written primarily to meet the needs of the experimenter and inventor who, when he considers applying for a patent in the United States, finds himself on unfamiliar ground.

The book is divided into five parts. Part 1 outlines the nature of a patentable invention and its relation to the prior art according to whether the invention is basic or is an improvement on other inventions. The procedure for applying for a patent is treated in some detail including the preliminary search; the preparation of the specification, drawings, and claims; the patent office action; and the probable cost of obtaining a simple patent. Interferences are discussed and the importance of recording the conception of an idea and showing diligence in following it up is emphasized. The question of patent agreements between employer and employees and the rights of each under varied conditions are mentioned. Advice is given concerning the selection of an attorney and the avoidance of certain classes of mail order attorneys.

Part 2 is concerned with the exploitation of the invention. It is shown that certain types of inventions are obviously most readily exploited by existing manufacturers or businesses in the particular field of the invention, while other inventions may be suitable for special exploitation. In the former event, advice is given for locating the most likely prospects and the questions of licenses, royalties, and promoter's fees are discussed with an indication as to how these matters are usually evaluated.

In case the invention is of such nature that it can be exploited on its own merits, suggestions are given as to how and where capital can be raised and advice is given as to the usual terms drawn up between the inventor and his financial backers.

This section also discusses briefly the question of foreign patents and shows a condensed summary of the patent laws of various foreign countries which includes the maximum term of the grant, whether the patents are taxed, and how soon the exclusive rights are lost if not used.

Information is also given concerning design patents.

Parts 3 and 4 discuss trade-marks and copyrights pointing out the similarities and differences as compared to patents. Information is given as to the procedure and cost of obtaining trade-marks and copyrights.

Part 5 contains a list of twenty-four suggested legal forms for petitions, oaths, assignments, etc. It also contains several pages of extracts from the patent laws of the United States.

The major sections are written in nontenchnical language but give a fairly comprehensive and accurate picture of the more important features of patent law.

*H. H. Beverage

* R.C.A. Communications, Inc., New York City.

"Perpetual Trouble Shooter's Manual—Volume VI," by John F. Rider, 1240 pages. Sold with booklet "Complete Index for Perpetual Trouble Shooter's Manuals, Volumes I, II, III, IV, V, and VI." Published by John F. Rider, 1440 Broadway, N.Y.C. Price $7.50.

This volume continues the loose-leaf series which has been published by the same author for the last few years. This series has become the leading source of circuit information and related data in the field of radio receiver servicing. The enormous amount of information in the volume may be seen from the fact that it contains 1240 8×11-inch pages, presenting data on the products of more than one hundred manufacturers. The arrangement is alphabetical by manufacturers.

The information given comprises circuits of the various models supplemented by more or less additional data, such as mechanical layout diagrams voltage readings, resistance values, alignment instructions and parts lists. In addition, there are instructions for the installation of automobile sets, and for the servicing of special equipment such as phonograph combinations, record changers and self-tuning receivers.

This volume gives the best available technical picture of the broadcast receiving art at the present time. It is therefore a valuable reference wherever the current practices in the broadcast receiver field are of interest. On account of the rapid development which has taken place in this field, it is likely that designers of receivers for other purposes may obtain valuable suggestions from broadcast receiver practice. It is well, however, not to rely on the merit of all the designs in the book, because poor as well as good design practice is exemplified in the various models of the various manufacturers.

Wherever information on present designs of broadcast receivers is desired, the present volume is to be recommended. This is especially so if the existing wide range of variation is of interest.

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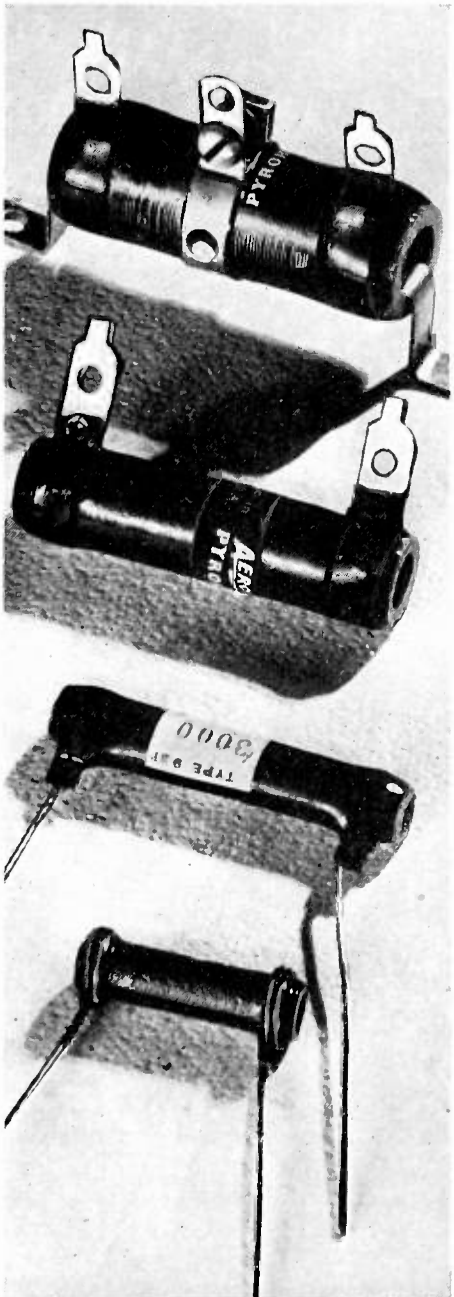

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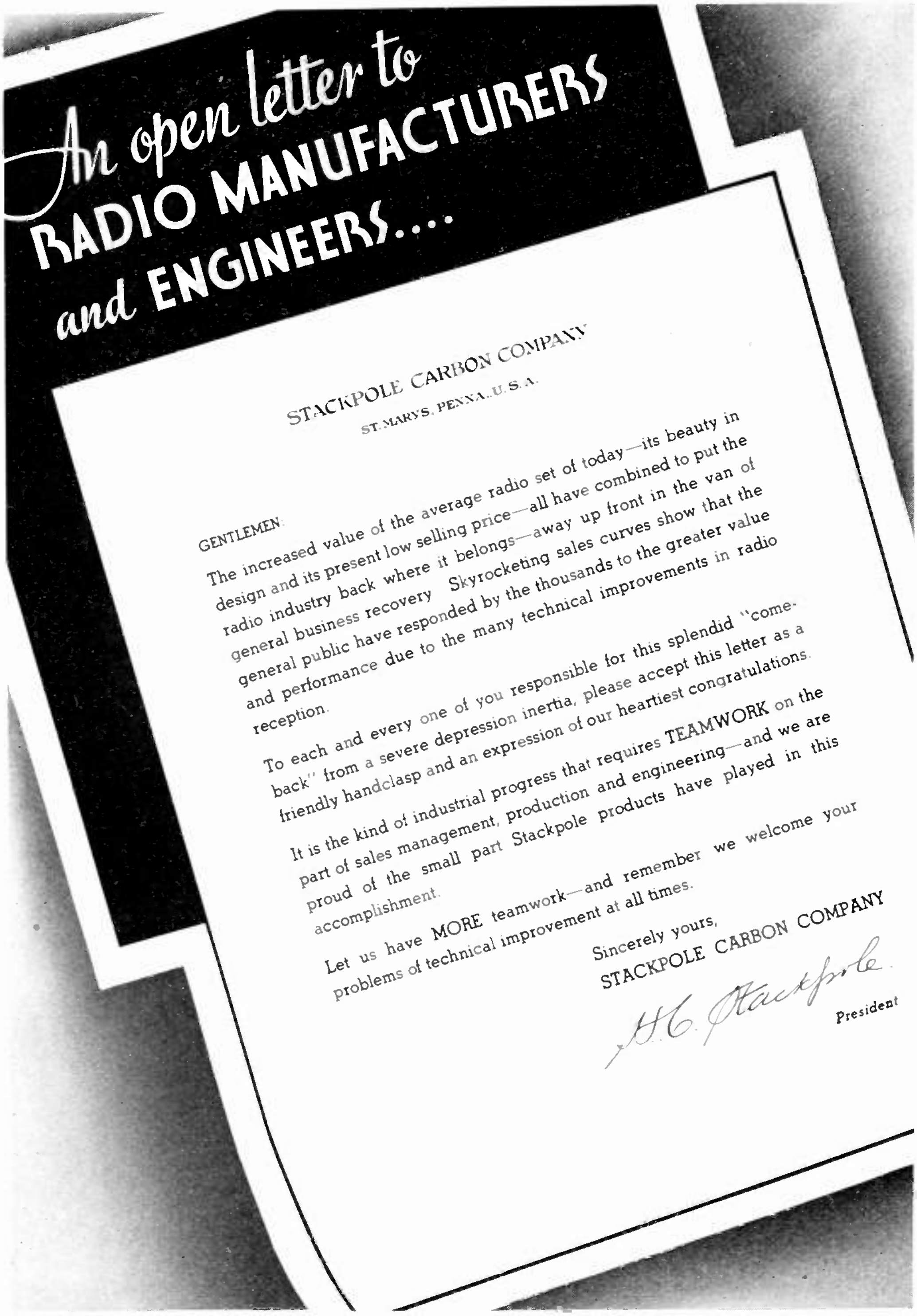

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President

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APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

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Gentlemen:

I hereby make application for Associate membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the members named below who are personally familiar with my work.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. Furthermore I agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

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(Address for mail)

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Mr. ....

Address ....

City and State ....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (c) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold any elective office specified in Article V. * * *

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ARTICLE IV—ENTRANCE FEE AND DUES

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Education ....

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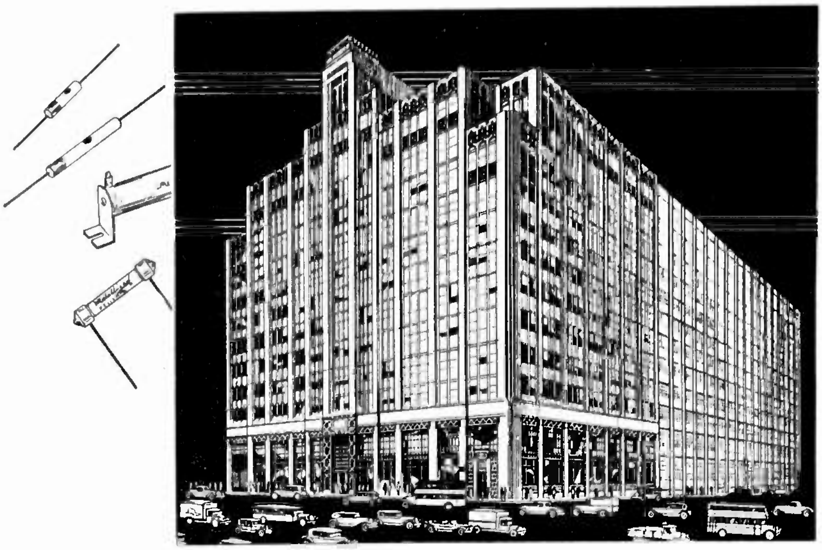

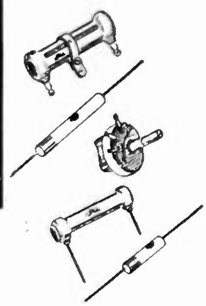

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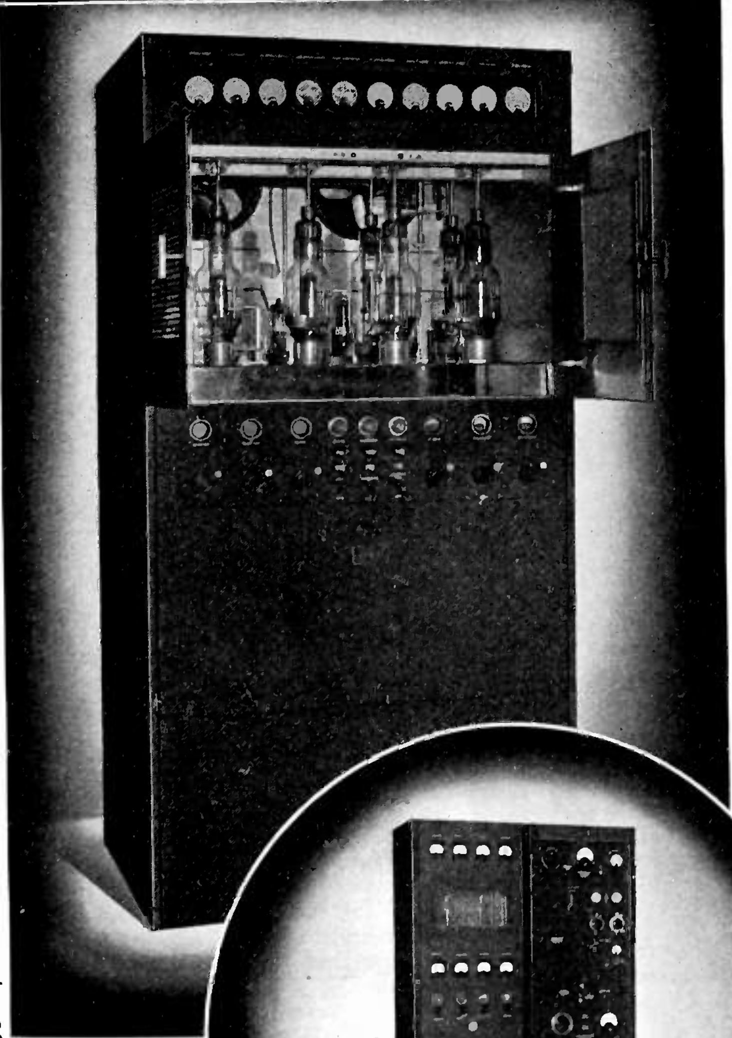

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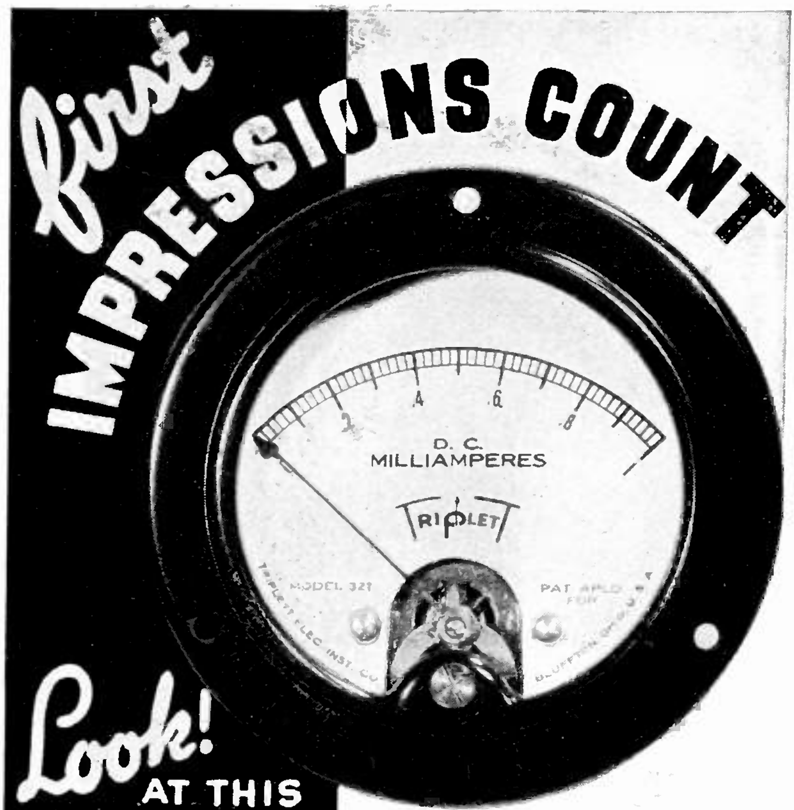

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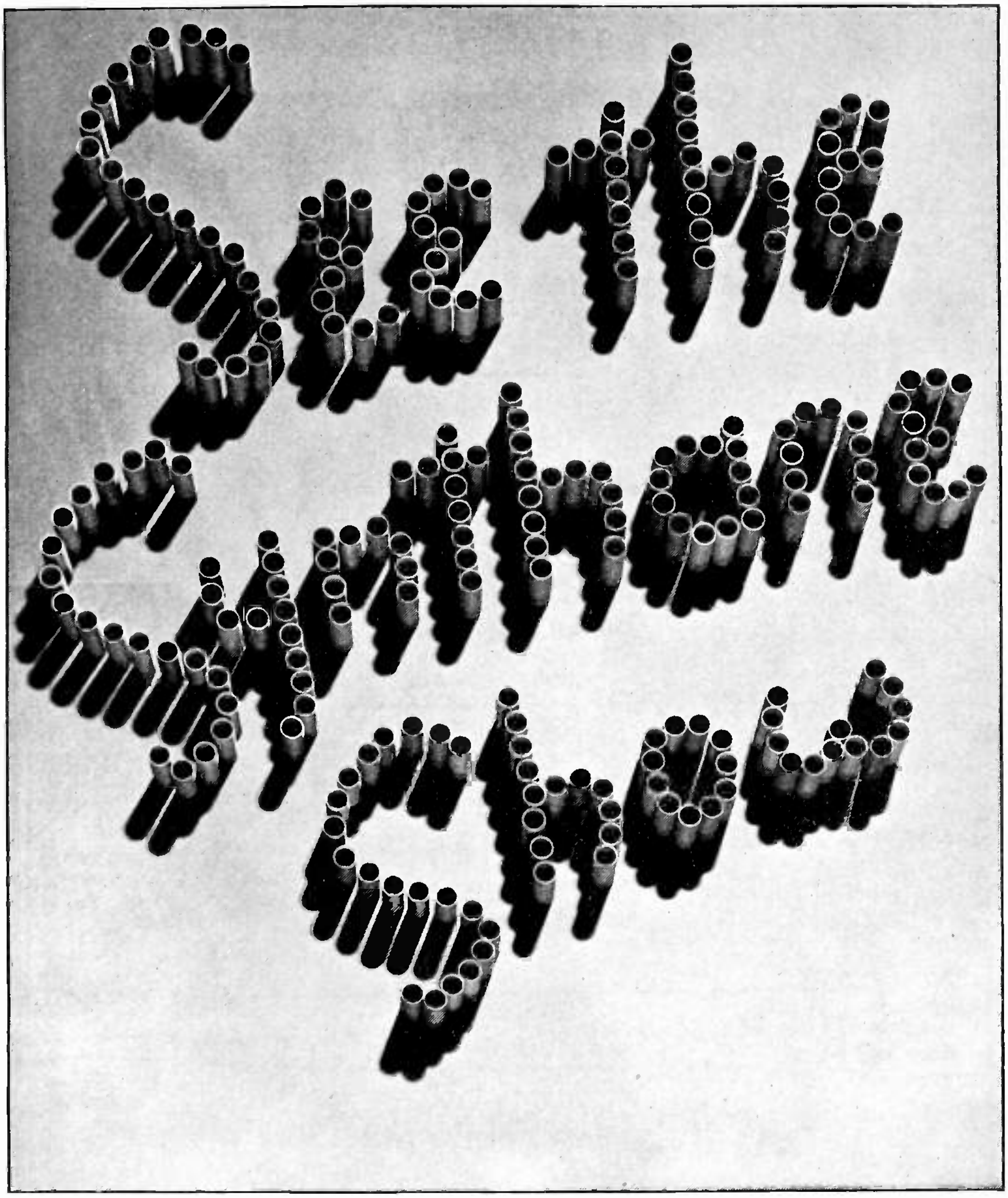
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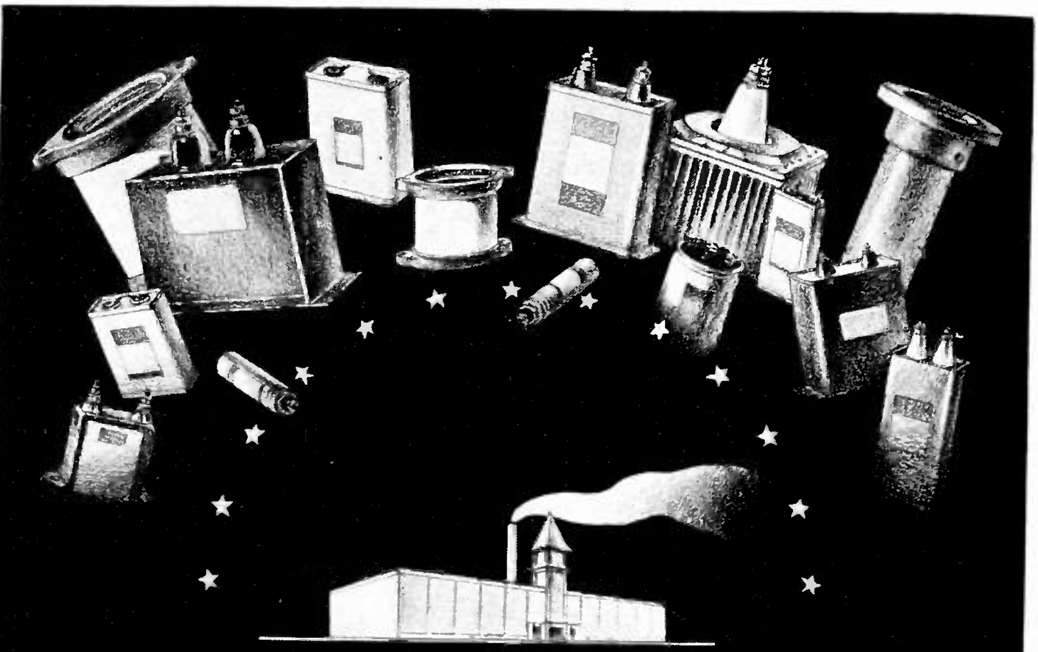

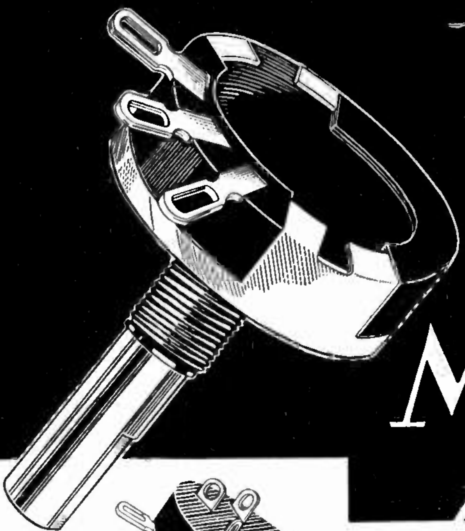

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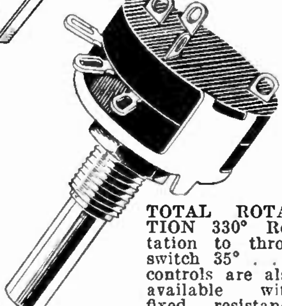
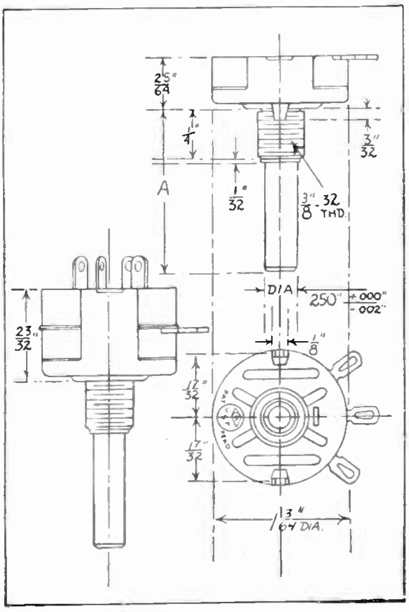


TOTAL ROTATION 330° Rotation to throw switch 35° . . . controls are also available with fixed resistance minimum. Total rotation then 280°



SWITCH DATA:

S.P.S.T.; D.P.S.T.; S.P.D.T.; four point. S.P.S.T. switches also available with dead lug. S.P.S.T. Switch rating: 3 amps. 125 volts; 1 amp. 250 volts; 10 amps. 12 volts.

With a given maximum resistance, the noise level of any good control will be in proportion to its resistor length. The longer the effective path of resistance, the lower the noise level.

We believe the new Centralab Midget has a lower noise level than any other small control because its resistor is 2 13/16 inches long—much longer than that of controls using the conventional flat horseshoe shaped resistor.

This length, so necessary for the gradual resistance change that gives good attenuation without noise is obtained by coiling a straight resistor strip on the inner circumference of the Bakelite case and by using 330° total rotation.

The MIDGET RADIOHM provides volume or tone control in single, twin or triple assemblies, as rheostat, potentiometer or with 1, 2, or 3 taps on resistance at choice of six different degrees of rotation. All assemblies available with or without Switch.

CENTRALAB Div. of Globe-Union Mfg. Co.

Milwaukee, Wisconsin

Centralab CRL

Volume Controls

Fixed Resistors

Wave Change Switches

Sound Projection Controls

EMPLOYMENT PAGE

ADMINISTRATIVE or executive position of responsibility wanted with engineering, manufacturing, or broadcasting organization by electrical engineer. Has university degrees in electrical engineering, has wide radio experience, several years university teaching, is interested in publicity and business end as well as technical, is now and always has been employed, but wishes to make change. Location preferably but not necessarily Canada or England. Box No. 154, c/o Institute of Radio Engineers.

B.S. in Electrical Engineering and graduate of radio school. Holds second class commercial radio operators license. Has had experience in laboratory work and in design and construction of transmitters and measuring equipment. Desires connection with research or design laboratory. Married. 23 years old. Box No. 155, c/o Institute of Radio Engineers.

B.A., 1933; B.S., 1934; and E.E., 1935 from Columbia, Sigma Xi and Tau Beta Pi. Experience on receiver and coil design and research on resistance of inductances at high frequencies. Has written several technical articles which were published. Desires research work or teaching, especially interested in coil design, high frequency electronics, frequency modulation and acoustics. Unmarried. 23 years old. Box No. 156, c/o Institute of Radio Engineers.

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